N66-10426

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum No. 33-243

Semiannual Review of

Research and Advanced Development

January 1, 1965 to June 30, 1965

Volume II. Supporting Research and Technology for the Office of Advanced Research and Technology National Aeronautics and Space Administration

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

August 15, 1965

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum No. 33-243

Semiannual Review of

Research and Advanced Development

January 1, 1965 to June 30, 1965

Volume II. Supporting Research and Technology for the Office of Advanced Research and Technology National Aeronautics and Space Administration

Frank E. Goddard, Jr.

Frank E. Goddard, Jr.
Assistant Laboratory Director for
Research and Advanced Development

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

August 15, 1965

Prepared Under Contract No. NAS 7-100
National Aeronautics & Space Administration

PREFACE

This document is prepared under the direction of the Office of Research and Advanced Development of the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California.

The Semiannual Review of Research and Advanced Development is published in three volumes directed to the appropriate NASA funding offices:

Volume I	Supporting Research and Technology for the Office of Space Sciences and Applications
Volume II	Supporting Research and Technology for the Office of Advanced Research and Technology
Volume III	Supporting Research and Technology for the Office of Tracking and Data Acquisition (New Systems and Spacecraft Subsystems)

This issue reports progress for the period of January 1, 1965 to June 30, 1965, Fiscal Year 1965.

Page Intentionally Left Blank

INTRODUCTION

This volume contains a review of all supporting research and technology in progress at the Jet Propulsion Laboratory during the period January 1, 1965 to June 30, 1965, under the direction of the Office of Research and Advanced Development, for the Office of Advanced Research and Technology.

The work units are arranged in numerical sequence by NASA code in each subject section. To locate a desired unit, refer to the Table of Contents under the appropriate heading.

Page Intentionally Left Blank

NUCLEAR ELECTRIC
SYSTEMS (120)

Page Intentionally Left Blank

ELECTRIC PROPULSION (120-26)

ELECTRIC PROPULSION APPLICATIONS
NASA Work Unit 120-26-04-01
JPL 320-60101-2-3830

NUCLEAR-ELECTRIC PROPULSION SYSTEMS

The primary objective of the FY 1965 nuclear-electric propulsion system studies was the self-contained operation of a complete thrustor module, including thrustor, feed system, controls, and power conditioning, using simulated power source inputs to the power conditioning. A cesium-bombardment thrustor was constructed, and its performance and plasma characteristics were mapped. Some striking differences between its plasma characteristics and those of a similar thrustor using mercury as the propellant were noted and reported in Ref. 1. A survey paper (Ref. 2) on the overall national status of electric propulsion component and system development was presented during this report period.

A zero-g feed system concept was formulated using positive expulsion tankage to make it compatible with either cesium or mercury operation. A storage vessel consisting of a metal tank and two center-mounted metal diaphragms was fabricated and tested for expulsion efficiency, pressure response, and compatibility with cesium. At this point, work was suspended in order to direct in-house efforts to support of the solar-electric feasibility study. It is anticipated that this work will be resumed about September 1965.

MERCURY ZERO-G FEED SYSTEM

An important aspect of the solar-electric feasibility study is the demonstration of a complete propulsion system module in a 500-hr life test. One of the most promising thrustors is the mercury bombardment ion engine, but to date there has been no development of a mercury zero-g propellant feed system. Funding limitations prohibited its development under the solar-electric contract, so in-house effort was redirected to fill this need.

A mercury zero-g feed system concept was generated, similar to the one already on hand for cesium. This system is shown schematically in Fig. 1. Its major elements include: (1) a positive expulsion type storage vessel, (2) a porous matrix vaporizer-phase separator, (3) a gas-pressurization system, including a pressure bottle and a step-down regulator. The major differences from the cesium system include the proposed use of elastomeric rather than metal diaphragms because of their compatibility with mercury and their more uniform pressure transmission, and the shift of the vapor interface from the interior of the vaporizer to its upstream end. The latter was found desirable because of the high surface tension and non-wetting properties of mercury. Operation is as follows: The vaporizer is heated to a pre-set temperature (about 350°C), and gas pressure is introduced behind the diaphragm to produce a pressure head in the liquid mercury which forces it to the hot vaporizer. Its entrance into the vaporizer is opposed by both the vapor pressure and surface tension forces. So long as the pressure head is greater than the vapor pressure of mercury at the vaporizer inlet temperature, and less than the combined effect of vapor pressure and surface tension pressure, the vaporization will take

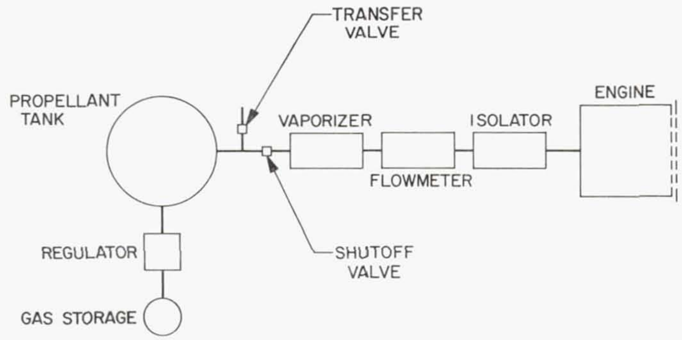


Fig. 1. Schematic of mercury zero-g feed system

place at the inlet. In practice, with the vaporizers being used, this means the liquid pressure head must be kept in the range of about 6 to 20 psi. A pressure transducer at the vaporizer inlet feeds back to the second stage of a two-stage pressure regulator to maintain the pressure head in this range. Under these conditions, flow rate is controlled by the temperature of the vaporizer and its impedence to gas flow. The latter can be somewhat varied by introducing a variable temperature gradient in the vaporizer. In Fig. 2 is shown the flow rate calculated for a typical vaporizer and the effect of a temperature gradient.

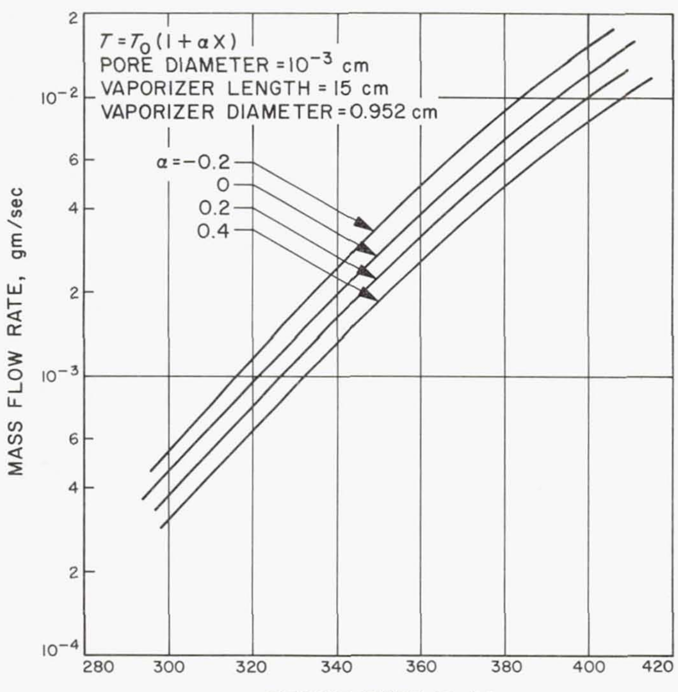


Fig. 2. Calculated flow rate as a function of inlet temperature and temperature in a typical vaporizer

Testing of a positive expulsion tank with metal diaphragms and a 6-in. -long vaporizer with a laboratory pressurization system is now proceeding. Details of the components and initial results are given in Ref. 3.

Storage vessels with elastomeric diaphragms are being fabricated. Two such vessels, made of fiberglass, are presently on hand, and will be tested in the feed system shortly. Fiberglass pressurization tanks are also on hand. Several candidate two-stage regulators are being investigated, and one or more will be procured within the next month for evaluation and incorporation into the feed system. Operation of an integrated engine and feed system is expected by the end of the summer.

SPACECRAFT STUDIES

The major objective of the FY 1965 program was to compare in some detail the conical-cylindrical versus flat-plane radiator configurations for a 300-kwe nuclear-electric spacecraft to be launched by a Saturn S-1B booster. The ground rules established for this study were:

1. Two reactor and power conversion system would be considered, the SNAP-50 with a turbogenerator and an all-liquid radiator, and a JPL reactor concept with a magnetohydrodynamic power converter and a condensing radiator.

2. Three nose cone angles would be considered for the shroud, 12.5, 15, and 20 deg.

3. Allowable dose rate at the payload was set at 10^{13} nvt and 10^{8} rad for 20,000 hr operation.

4. Weights of radiator, shield, and requisite structure would be calculated.

Radiators were designed for the three loop (all-liquid radiator) system for all configurations using both beryllium-columbium and copper-stainless steel construction. In all cases, the flat plane concept gave the lightest weights (Fig. 3), although in absolute pounds the difference was relatively small. The radiator designs were based on rectangular rather than tapered fins because the weight penalty was small compared with the fabrication problem. In all cases, also, the larger nose cone angle (and hence shorter spacecraft length) was found to be most advantageous.

Shielding calculations for this system were made, but lack of manpower made the shielding calculations less accurate than is considered desirable for this study. While absolute weights could not be determined to better than about ±50%, comparative weights and weight differences are thought to be much more accurate, and gross trends were readily apparent. In all cases, the shield weights for the cylindrical radiators were about 1,500 lb heavier than for the flat plane configuration, for the same nose cone angle. Shield weights also tended to drop as the nose cone angle was reduced (i. e., with longer spacecraft). Shield weight estimates are shown in Fig. 4. During the coming year, it is planned to contract out the shielding calculations to obtain more definitive results.

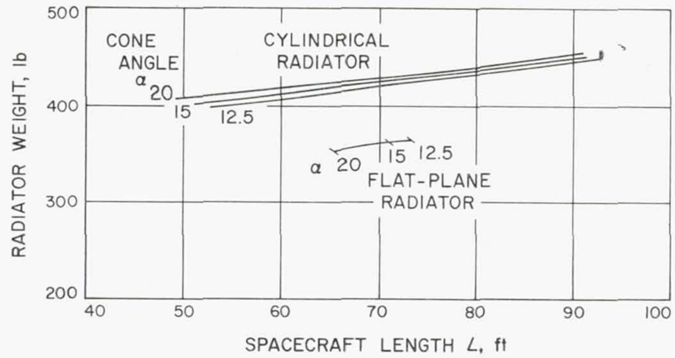


Fig. 3. Radiator weights for flat-plane and cylindrical radiator configuration

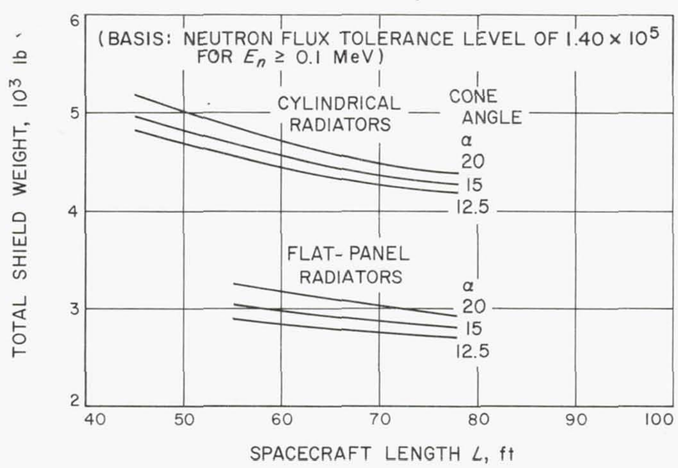


Fig. 4. Estimated shield weights for flat-plane and cylindrical radiator configurations

Shroud weights were obtained from the launch vehicles office and were found to vary from 4,500 lb for the shortest spacecraft (20-deg nose cone angle, 65-ft spacecraft) to 6,000 lb for the longest spacecraft (12.5-deg nose cone angle, 73-ft spacecraft). Since shroud weight trades off against spacecraft weight at a ratio of 7.5:1 for the boost vehicle considered, provided the shroud is jettisoned at first stage burnout, this represents a 200-lb weight penalty for the longer spacecraft. The low radiator weight (~400 lb for beryllium-columbium and 900 lb for copper-stainless) also indicates it would be undesirable to incorporate the shroud with the radiator, as has been suggested for the cylindrical configurations, although this is not clear since the shroud weight would be reduced if it could be supported partially by the spacecraft. A detailed analysis of this tradeoff is yet to be made.

Results of the structural analysis are not yet available. The structures being considered for the two configurations are shown in Fig. 5. For this study, structures are being calculated to support the reactor, shield, radiators and power conversion equipment. Initial estimates indicate no substantial difference between the cylindrical and flat plane structural weight requirements, and a relatively strong dependence on spacecraft weight. The preliminary analysis of the structure will be completed by the end of June 1965, and factored into the overall weight comparison. The results of this initial phase of the study will be presented at the AIAA Annual Meeting, July 26-29, 1965 (Ref. 4).

Analysis of the condensing radiator system will next be pursued. More refined shielding calculations are planned to reduce the present uncertainty in the estimated shield weights. Estimated thermal environments are being used in making the structure weight calculations; a thermal analysis of the spacecraft will be performed to verify these estimates, and any corrections necessary to structural weight estimates will be calculated.

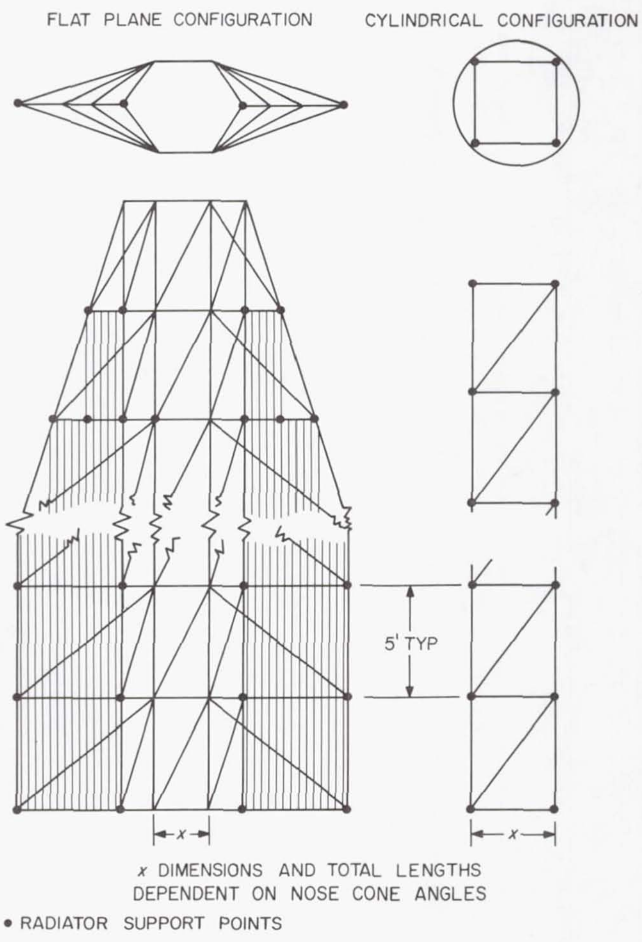


Fig. 5. Assumed structural configurations for determination of structure weights

REFERENCES

1. Masek, J. D., Kerrisk, D.J., "Plasma Characteristics for Mercury and Cesium Bombardment Ion Engines," SPS 37-32, Vol. IV, pp 141-148, covering the period February 1 to March 31, 1965.

2. Kerrisk, D.J., "State-of-the-Art of Electric Propulsion," Space Electronics Symposium, Vol. 6, American Astronautical Society, 1965.

3. Kerrisk, D.J., Masek, T.D., "Zero Gravity Feed Systems for Mercury Ion Engines," SPS 37-33, Vol. IV, covering the period April 1 to May 31, 1965.

4. Volkoff, J.J., Womack, J.R., "Preliminary Investigations to Determine Nuclear-Electric Spacecraft Configurations for High Energy Missions," (to be presented at the AIAA Annual Meeting, July 26-29, 1965).

SOLAR-ELECTRIC PROPULSION STUDY
NASA Work Unit 120-26-04-03
JPL 320-60501-2-3830

A study of the feasibility of solar-powered electric propulsion spacecraft has been initiated jointly by NASA and USAF, with JPL responsible for technical management. The study includes the evaluation of large solar arrays, the development and test of electric propulsion systems, the design and analysis of conceptual spacecraft, and the analysis of missions, reliability, and cost. An organization chart is shown in Fig. 1.

The feasibility study is contractually complex. Two parallel spacecraft system studies are provided. Electro-Optical Systems (EOS), Inc. is conducting a study under USAF contract, and Hughes Aircraft Company (HAC) is conducting a study under JPL contract. Interchange of information is effected through JPL only and is limited to maintaining common interfaces with spacecraft subsystems such as the solar arrays, space sciences, and others.

The lightweight solar arrays are being studied at the Boeing Company under JPL contract (Ref. 1). This includes configuration and design studies, and the fabrication and test of sample solar panels and array models.

Propulsion systems under consideration in the study include the cesium contact and cesium bombardment ion engines at EOS and the mercury bombardment engine at Hughes. Thrustors are being developed under USAF and NASA Lewis contracts, and the system hardware is being developed under JPL contract.

CONTRACTUAL ACTIVITY

An RFP was issued for spacecraft feasibility study and propulsion system design concurrently with a Division 34 RFP for solar array feasibility study. Coordination with USAF and NASA-LeRC was conducted through NASA Headquarters, Nuclear System and Space Power Division. NASA Headquarters, LeRC, and JPL evaluated the feasibility study proposals, and selected the HAC as the successful bidder. NASA Headquarters further directed JPL to negotiate a contract with EOS for design of power conditioning and controls, and also transferred $45, 000 to the USAF for support of propulsion system integration at EOS.

An 8-mo study contract was negotiated with Hughes, in the amount of $331, 500, covering spacecraft feasibility study and propulsion system design. A 4-mo contract was negotiated with EOS, in the amount of $91, 500, also for propulsion system design. Competitive evaluation of the Hughes and EOS designs is now in progress to select a single NASA contractor for fabrication and test of a complete propulsion system. An additional system fabrication and test is provided at EOS under USAF contract.

Since initiation of the feasibility study with HAC, it has been determined that an increased level of effort is needed. An approximate 1-mo stretchout and increased liaison is needed for coordination with the solar array contractor; additional propulsion system design is needed for an alternate ion engine with a developmental cathode; spacecraft integration analysis requires greater depth of study; and Hughes has been

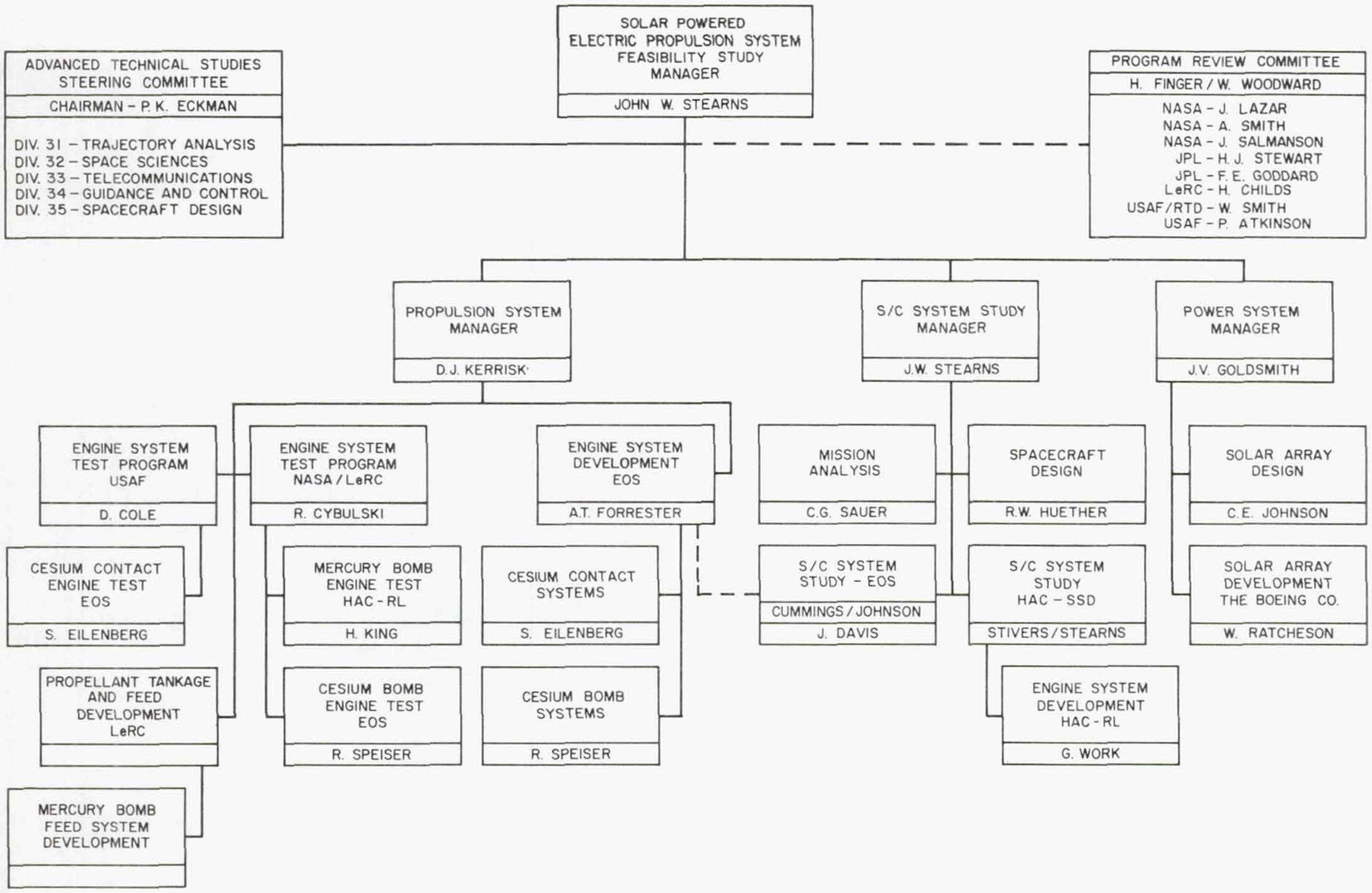


Fig. 1. Organization of solar-electric propulsion study

directed to assume major responsibility for the Mars mission analysis. A proposal by HAC, in the amount of $178,000 is under negotiation at this time.

TECHNICAL PROGRESS

A first-iteration spacecraft configuration and mission analysis were completed during the first 6-wk of the solar-electric system study. This provided a gross check of spacecraft and mission feasibility expectations, and identified the major system problem areas. In addition, the initial spacecraft iteration was necessary to determine the system constraints to be imposed on the propulsion system design.

The study contractors briefed the NASA/USAF Program Review Committee at the conclusion of the first-iteration study and were directed to proceed with their approaches outlined for the remainder of the studies. Technical results from Hughes are presented in a bimonthly report to JPL (Ref. 2). An additional interim report covers the propulsion test system design. The EOS design contract is reported in an interim report (Ref. 3) and final report (Ref. 4).

System contractors are now approaching the point where preliminary subsystem interface requirements for the spacecraft are defined. Documentation is to be provided in a requirements and criteria document. Detailed interface definition

will be followed by a second-iteration conceptual spacecraft design study, at the conclusion of which another briefing will be made to the Program Review Committee.

Mission analysis at JPL is being expanded to cover systematic errors, orbit determination, and failure mode analysis for solar-powered electric propulsion spacecraft to Mars. In addition, preliminary analyses are to be made of the Jupiter and Mercury mission potential.

Expected completion of contractual studies is the second quarter of FY 1966, with contractor briefings at JPL and NASA. The JPL Advanced Technical Studies Steering Committee will review and critique the study results and make recommendations to NASA with regard to the applications potential of solar-powered electric propulsion.

REFERENCES

1. Boeing Company Bi-Monthly Report No. 1, Fabrication Feasibility Study of a 20 Watt Per Pound Solar Array, No. D2-23942-1 (Contract 951132).

2. Hughes Aircraft Company Bi-Monthly Report, May 1965 (Contract 951144).

3. Electro-Optical Systems Interim Design and Development Report 6780-IR-1, June 1, 1965.

4. Electro-Optical Systems Final Report 6780, Power Conditioning and Control System, July 1, 1965.

Page Intentionally Left Blank

NUCLEAR ELECTRIC POWER (120-27)

NUCLEAR SYSTEM DEFINITION STUDIES
NASA Work Unit 120-27-06-01
JPL 320-70101-2-3420

PROGRAM REDIRECTION

During the second half of FY 1965 the nuclear definition studies program at JPL continued in its efforts to contribute to the definition and solution of the problems associated with the design and integration of radio-isotope fueled power sources into planetary spacecraft and capsules. It was originally intended that this objective would be carried out through in-house testing, contractor studies, and review and analysis of the state of the art of the thermoelectric industry. However, a redirection in the program was necessary because many of the proposed contracted studies would have paralleled existing efforts of other government agencies and there was a lack of the required performance data of thermoelectric generators. It appeared that JPL could better serve its needs by utilizing its resources to establish a testing program in order to better understand the design characteristics and limitations of thermoelectric power systems. Under this program, evaluation testing was conducted during FY 1965 on a SNAP II and a 5-w GeSi thermoelectric module.

PROGRAM ACTIVITIES

A detailed thermoelectric program plan was completed early in FY 1965. This was followed by procurement of thermoelectric modules for life testing and equipment and instrumentation for monitoring the tests. After a review and evaluation of all known manufaturers of thermoelectric devices, three contractors were selected to deliver one thermoelectric generator each. RCA was awarded a contract to supply a 15-w, silicon-germanium thermoelectric generator (Fig. 1). Westinghouse Electric Corporation is currently engaged in negotiations with JPL to supply a 20-w lead-telluride thermoelectric generator (Fig. 2). Monsanto Research Corporation is presently negotiating with JPL for supplying a 20-w high-temperature thermoelectric generator. The RCA generator is scheduled for delivery by August 15, 1965. Delivery of the Westinghouse and Monsanto generators are anticipated by December 1, 1965 and March 1, 1966, respectively. Preparation of processing and testing specifications and flow plans has been initiated for evaluation of these modules upon their receipt by JPL. Life testing of the three previously mentioned thermoelectric generators will continue during FY 1966. Data will be accumulated, reduced, and presented in parametric form at regular intervals.

Four thermoelectric test stations (Fig. 3) and two control monitoring consoles (Fig. 4) have been procured and are currently being assembled for operation. In addition, a fully serviced laboratory facility is being prepared to accommodate these test stations. Enlargement of the in-house testing program to include environmental testing of thermoelectric modules and couples such as shock, vibration, and thermal cycling is being planned for the second half of FY 1966. Selected study contracts will be let during the year to aid in the further definition of requirements and design details affecting the integration of radioisotope thermoelectric power systems for specific spacecraft missions being considered by JPL.

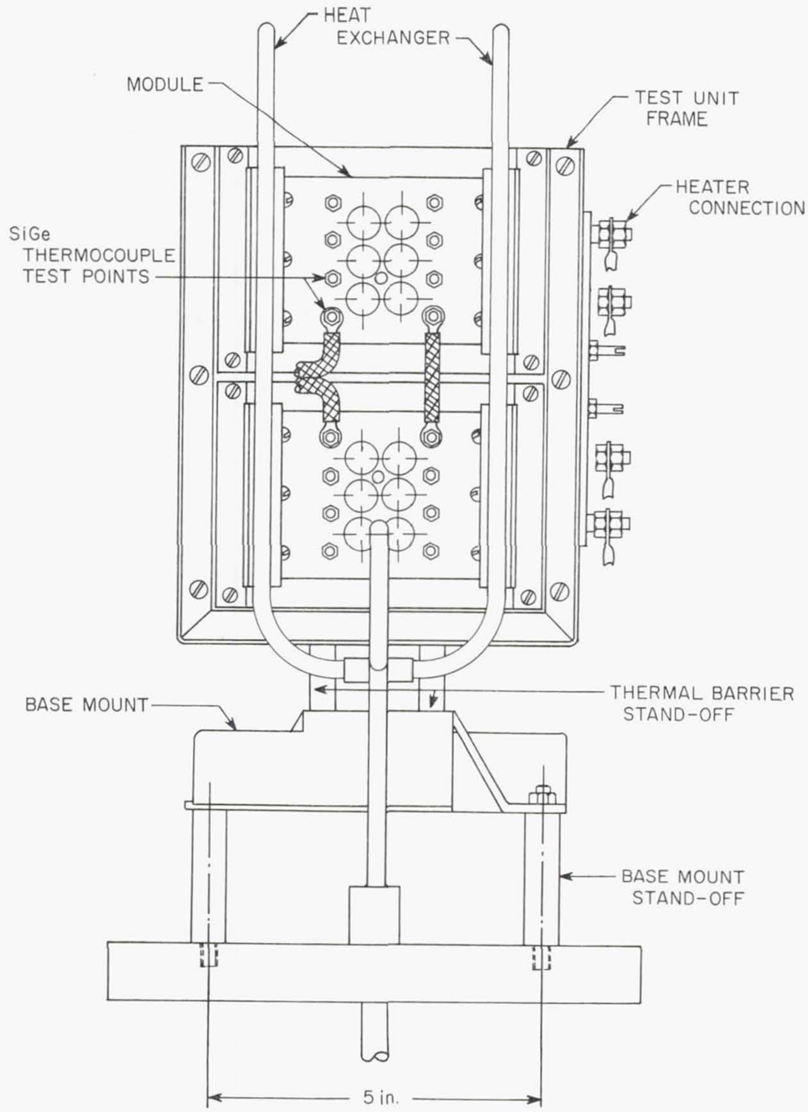


Fig. 1. RCA thermoelectric test unit assembly — side view

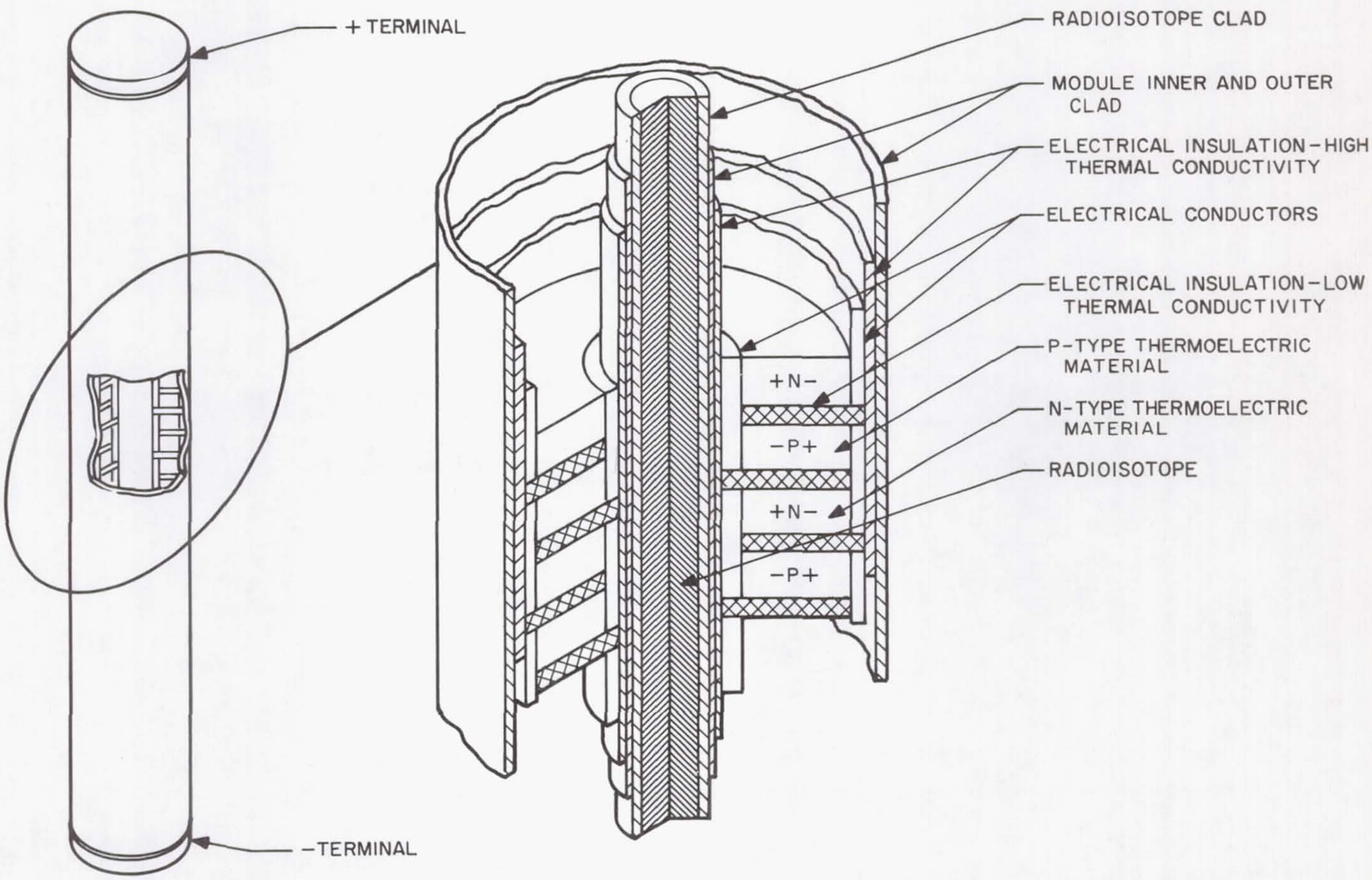


Fig. 2. Westinghouse tabular thermoelectric module with radioisotope source

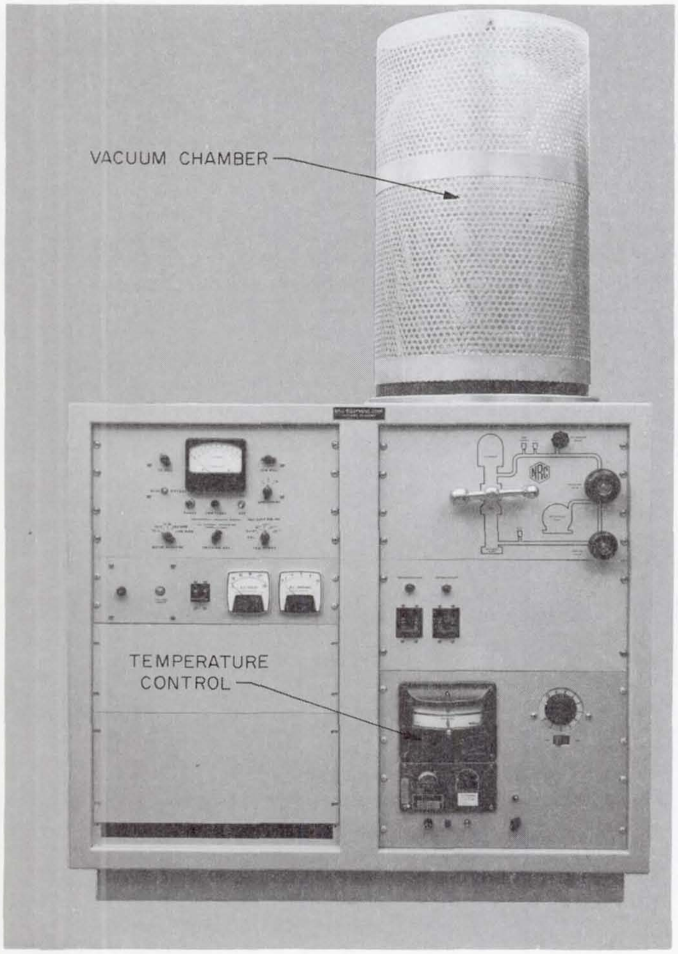


Fig. 3. Thermoelectric test station

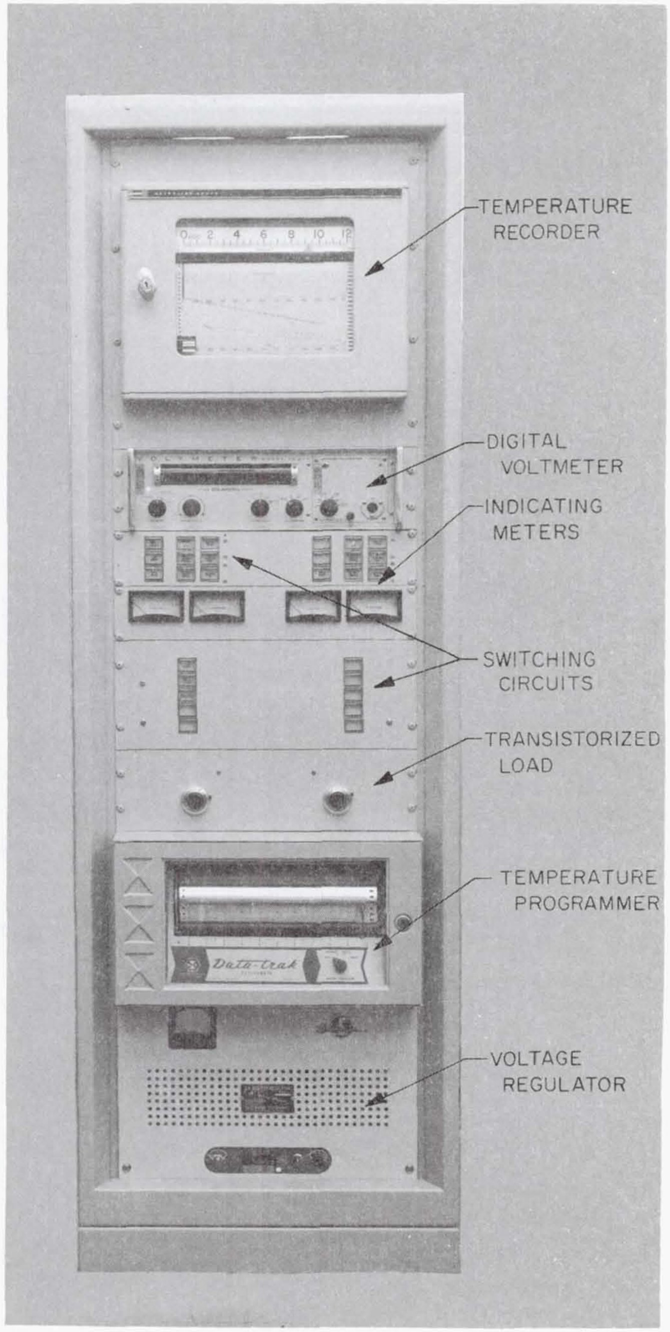


Fig. 4. Control monitoring console

LIQUID METAL SYSTEMS & NUCLEAR REACTOR POWER STUDIES
NASA Work Unit 120-27-06-02 and 120-27-06-05
JPL 320-70201-2-3830 and 320-70501-2-3830

LITHIUM-BOILING POTASSIUM LOOP

All components have been received and the final EB weld closures made on the boiler. Activities currently in progress include component fit-up on the loop frame, installation of tungsten-rhenium thermocouples on the loop, and partial application of zirconium and tantalum protective foil wraps on the loop. These activities will be completed after all field welds have been made. The development of the relatively unique attachment procedures for the thermocouples will be the subject of a contribution to the SPS. During the next report period, loop fabrication, checkout, and startup will be accomplished and operation and data analysis will have commenced. A crossflow boiler (boiling on shell side of tubes) will be designed and built. Inspection of turbine wheel and liquid metal bearings will also be conducted during the next period, if a shutdown is necessitated for other reasons.

A final report (Ref. 1) by Geoscience, Ltd. was received in February 1965. This report covered the work accomplished under JPL Contract No. 950946 to Geoscience, Ltd, Solano Beach, California. The purpose of the study program was to investigate the overall steady state and transient performance characteristics of a binary Rankine cycle utilizing potassium and lithium as working fluids. Steady state and dynamic, thermal and hydraulic relationships were derived for the components of the system, based upon its physical dimensions, characteristics and materials.

The fundamental heat transfer and fluid flow equations that describe the system are presented in the report and evaluated over a stipulated range of parameters. Heat transfer conductances, wall and fluid temperatures, pressure drops, and thermal and hydrodynamic time constants are presented. The results of the study verify similar studies undertaken in-house and present an overall system description.

A second contract to Geoscience for a dynamic analysis of the loop was let in March. The objectives of the new contract, which is basically an extension of the first, are to write the dynamic equations of the loop for use in the analog simulation now under way. The first month's progress report from Geoscience has been received. A model of a simplified loop was derived and a parameter study was presented in the form of performance maps. Additional analog studies in-house have been initiated. The preheater section of the boiler was programmed and the results appeared satisfactory. These studies will continue during the next period.

MATERIALS

The tilting capsule tests on 321 and 410 stainless steel have been completed except for rerun capsules. Evaluation of results is progressing. Tensile testing and microprobes analysis on several of the samples have been completed. Data will be presented in the SPS upon completion of the rerun tests. Reflux testing of stainless steel capsules has begun.

Fabrication of test capsules to investigate interaction of various refractory metals in alkali metal environment has been initiated.

Testing of the stainless steel capsules will be continued, as will the fabrication and testing of the refractory metal capsules. Installation and operation of an electron beam welding facility is in progress.

An initial draft of a survey on high temperature nuclear fuels is in preparation. The JPL library is preparing a literature search on nuclear fuels. These efforts will be coordinated with a JPL subcontracted survey now under negotiation.

Compatibility tests of O-rings of alkali metal have been completed and indicate that Buna N is satisfactory for potassium applications and that fluorosilicone rubber is satisfactory for both potassium and lithium. Complete data from these tests will be presented in the SPS.

SURVEY OF INDUSTRY PROPOSED THERMIONIC REACTOR SYSTEMS

The initial survey of industry proposed thermionic reactor systems has been completed and a report is in preparation. This study covers in-pile thermionic concepts only and aims at assessing the present status of such systems. Field trips to General Atomic, San Diego, California, and General Electric, Vallecitos, California, were taken. Also, an AEC-sponsored classified symposium in Germantown, Maryland, during May 13 and 14, was attended. These visits are reported in JPL Conference Reports.

Not all topics will be covered in equal depth in the final report, which will be completed in July 1965. Emphasis will be placed on the thermionic elements and reactor physics.

STABILITY OF NUCLEAR THERMIONIC SYSTEMS

The unique control and stability problems associated with a nuclear thermionic power plant are under study. System equations have been written and have been put up on the analog computer (Ref. 2). This work was essentially finished by the end of June 1965. Simple test problems, involving two temperature regions only, gave results in accordance with analytical results. The analog simulation of the relatively complicated nonlinear equations are expected to give hints on how to properly simplify the equations, thus making them amenable to analytical solution and subsequent development of design criteria. The reactor with reflector, electric circuit, and coolant loops have been simulated. Detailed calculations will start FY 1966. At the present, only the time variable is kept independent. Spatial effects will be studied by using a simple digital computer routine that directly translates the analog simulation. The digital machine becomes more practical when dealing with partial differential equations. The stability study is expected to yield formal reports during FY 1966.

A symposium on neutron Dynamics and Control, April 5-7, 1965, in Tucson, Arizona, sponsored jointly by the University of Arizona and the AEC, was attended. The American Nuclear Society (ANS) Annual Meeting during June 21-24, 1965, was also attended. Review reports are in preparation.

For calculation of neutron distributions and derivation of appropriate cross sections, the following codes were obtained and developed:

GAM-II	Neutron multigroup cross sections from General Atomics, San Diego, California.
2-DTF	Advanced neutron transport code for two-dimensional calculations, from United Nuclear Corp., White Plains, New York.
DF-II	Advanced neutron transport code for one-dimension, from Atomic International, Canoga Park, California.
BENT	Exact solution of the Boltzmann neutron transport equation in one-dimension and for one energy group, developed in-house and described in a JPL report being readied for publication.

REFERENCES

1. Geoscience, Ltd., Report No. GLR-31, Steady State and Transient Performance of a Binary Rankine Cycle Utilizing Potassium and Lithium as Working Fluids, February 1965.

2. H. Gronroos, "Variational Equations for Reactor Kinetics With Feedback Terms," JPL SPS No. 37-32, Vol. IV, covering the period February 1 to March 31, 1965.

Page Intentionally Left Blank

MHD CONVERSION SYSTEMS
NASA Work Unit 120-27-06-03
JPL 320-70301-1-3830

HYDRAULIC INVESTIGATIONS

Progress

Closed-loop circulation of liquid metal was achieved using eutectic sodium-potassium alloy (NaK) as the liquid metal and nitrogen as the driving gas. The test system, Fig. 1, was essentially a conversion system without a generator; the net fluid power available for electric power production was dissipated through incomplete pressure recovery in the diffuser. The NaK simulated the 2000°F liquid lithium in a space conversion system and the nitrogen simulated the cesium vapor.

To operate the system, the nitrogen flow was first started. Then NaK was pressure-fed from the start tank to the injector at 120 psia. The resulting two-phase NaK-nitrogen mixture expanded through the nozzle to atmospheric pressure and the nitrogen was separated by the conical separator and exhausted, with about 0.7% of the NaK, to a scrubber outside the test cell. The NaK flowed through the annular channel that would form the generator in a conversion system and left the diffuser at a pressure higher than the injector pressure. As a result, the NaK was able to return to the injector through the return lines, opening the check valves that had been preventing backflow from the injector and closing the check valves in the start-tank feed lines. (A similar starting method would be employed in a cesium-lithium conversion system with the conversion system and reactor preheated to 2000°F and the lithium inventory held at 2000°F in the start tank. The system would be capable of closed-loop operation for about 10 sec using the heat capacity of the lithium, allowing that much time to establish reactor power.)

In the NaK-nitrogen tests, the system reached steady closed-loop operation within 3 sec after initiation of the starting flow. The operating behavior was essentially the same as previously obtained with water and nitrogen, differing only due to the 12% lower density of NaK. Operation was smooth and stable over the range of nozzle inlet pressures from 130 psia to 230 psia and NaK flow rates from 70 to 200 lb/sec. The operating conditions at the maximum power point reached are presented in Table 1 and compared with the operating conditions for a 300-kw cesium-lithium system.

An alternative separator configuration, the "flat" or "two-dimensional" separator, shown in Fig. 2, was found to give performance equal to the conical separator in tests with water and nitrogen. The approximately threefold reduction in the width-to-gap ratio of the exit channel with the flat separator would reduce the friction loss in the generator and make it easier to obtain the 60-70% generator efficiency required. Also, a flat separator and generator would be simpler to fabricate. For these reasons, it has been decided to change to the flat configuration in subsequent work.

Another avenue for reducing generator friction was revealed in tests which showed that injecting gas between the liquid and the wall in the generator channel reduced the wall shear by a factor of two or more. This technique should also flatten the liquid velocity profile and reduce electrical boundary layer losses.

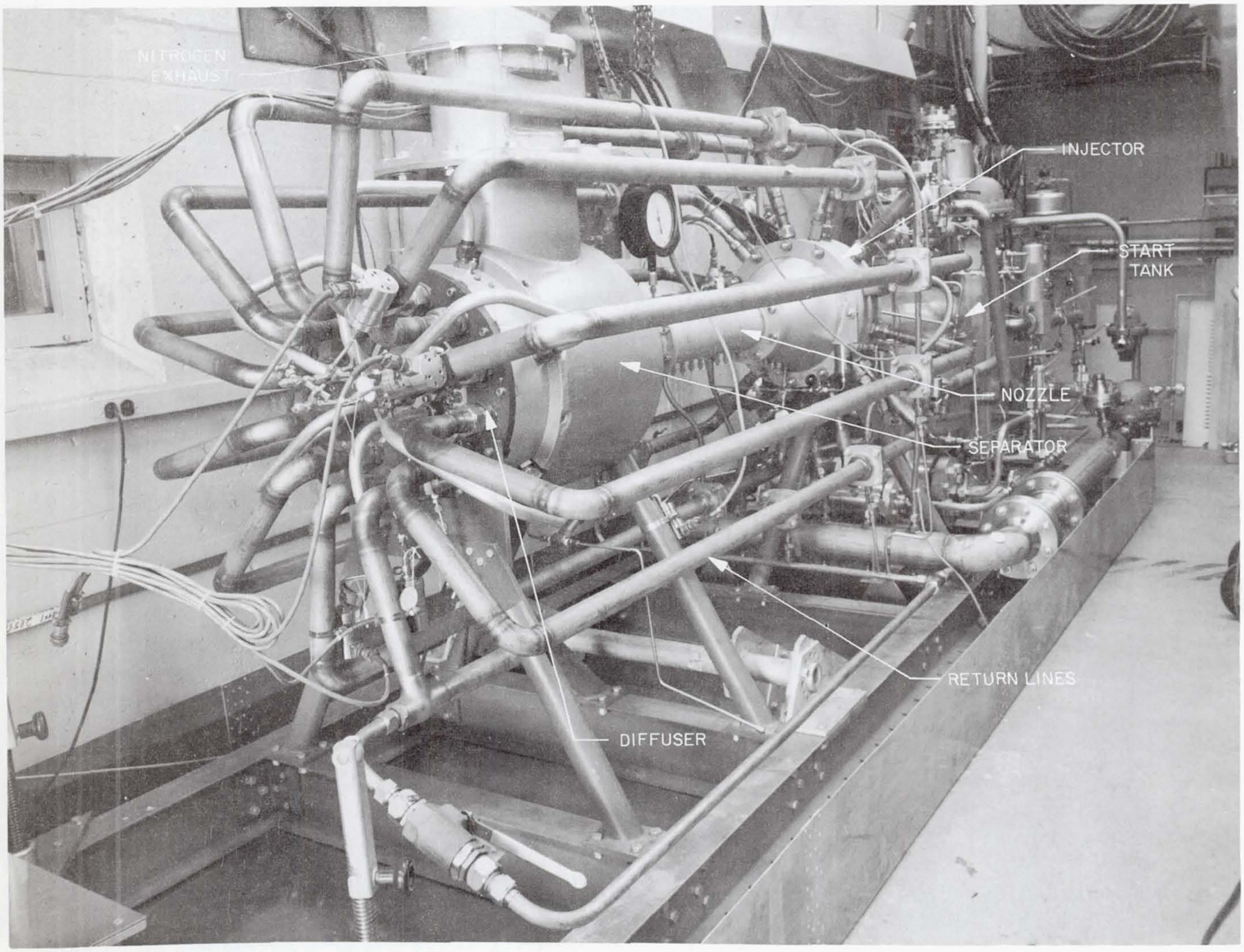


Fig. 1. Test system for closed-loop circulation of liquid metal

A final series of experiments with the supersonic two-phase tunnel is in progress following a detailed survey of the inlet velocity and void-fraction profiles. Completion of the present test series will provide sufficient data for a definitive thesis on supersonic two-phase flow by the California Institute of Technology graduate student conducting this investigation.

Detailed results of the hydraulic investigations were reported in Ref. 1-3.

Computer programs for two-phase nozzle flow and cycle performance have been written and are in use for comparison of different working fluids, operating conditions, and cycle arrangements.

Plans

A new closed-loop system utilizing the flat separator and incorporating a generator will be fabricated during the next six months. An ac generator will be

employed if the ac work progresses rapidly enough; otherwise, a dc generator of 3-4 v output will be employed to obtain an early integrated test.

The two-phase tunnel will be employed to study supersonic diffuser flow under dissolving-gas conditions, as in a cesium-lithium system, by employing carbon dioxide in place of nitrogen.

GENERATOR INVESTIGATIONS

Progress

A method was found for eliminating, in principle, the end losses in an ac generator by employing compensating poles at each end to cancel out all changes in flux linkage in the fluid other than due to slip. This technique should permit

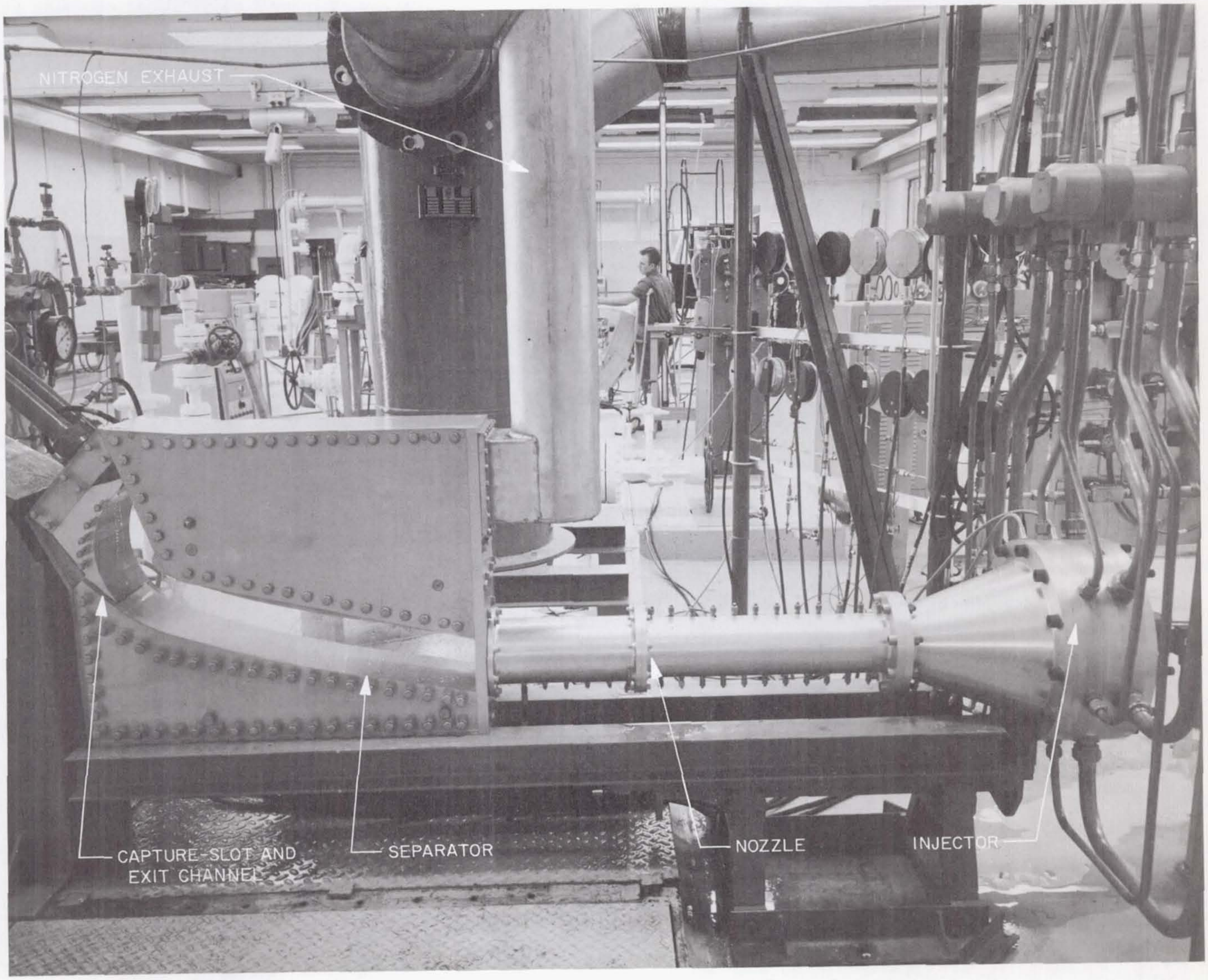


Fig. 2. "Flat" or "two-dimensional" separator

Table 1. Operating conditions of NaK-nitrogen closed-loop system and comparison with 300-kw cesium-lithium conversion system

	NaK-nitrogen[a]	Cesium-lithium
Nozzle inlet temperature, °F	52	2000
Nozzle inlet pressure, psia	230	230
Nozzle exit pressure, psia	23	25
Diffuser exit pressure, psia	255	245
Gas flow rate, lb/sec	6.6	17
Liquid flow rate, lb/sec	188	145
Nozzle exit velocity, ft/sec	377	557
Separator exit velocity, ft/sec	293	500
Diffuser inlet velocity, ft/sec	203[b]	290
Available fluid power, kw	82	430

[a]First six items measured; remainder inferred from measurements and water-nitrogen calibrations.

[b]Required value; actual velocity was higher since no generator was present.

attainment of the desired 60-70% efficiency level with the short generator lengths required.

To verify the compensating pole principle, an experimental 5-kw ac generator is being fabricated for testing with NaK in September. Figure 3 shows the stator blocks and their windings, positioned with the 0.1-in. gap they will have when mated with the flow channel. The inner slots and teeth form the one-wavelength, three-phase, 1000-cps traveling-wave winding, and the wider teeth at each end form the compensating poles.

An analysis of the performance capability of ac generators in a 300-kw cesium-lithium system showed that an efficiency of 60% should realistically be attainable. This analysis, and a more detailed description of the 5-kw ac generator, was presented in Ref. 3.

A final report on the results of the earlier dc generator investigation was published in Ref. 4.

Plans

Designs of both ac and dc generators will be prepared for the closed-loop system, and the ac design will be the one fabricated if results of the 5-kw generator tests are favorable.

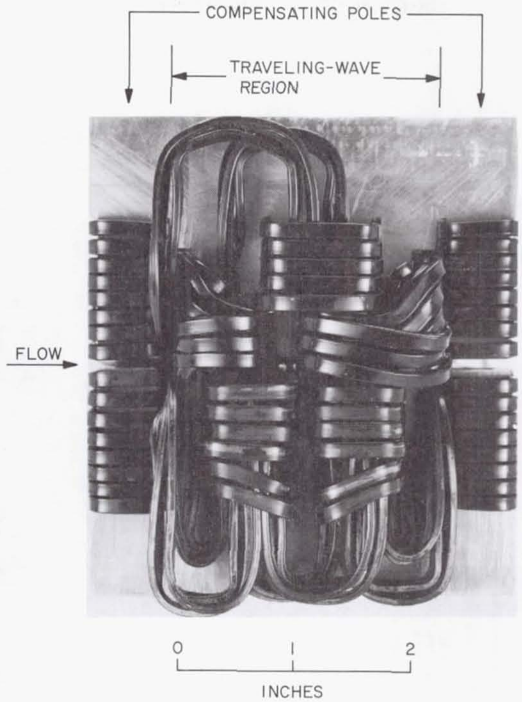


Fig. 3. Stator blocks and windings

Design studies will be initiated on generators for 2000°F cesium-lithium systems to uncover the heat transfer and insulation design problems, and thermal test mockups will be prepared for testing in the 100-kw loop.

TEST FACILITY CONSTRUCTION

Progress

The containment tank for the 2000°F 100-kw cesium-lithium erosion loop, Fig. 4, has been baked out and a preliminary lithium erosion loop, incorporating only the lithium pump circuit, has been installed for initial testing. Several candidate separator materials are located in a 250-ft/sec section of the lithium loop.

Design of the final loop configuration, incorporating a cesium-lithium two-phase nozzle to accelerate the lithium to 600 ft/sec, has been completed, and the Cb-1Zr nozzle and piping are being assembled.

A 1-ft segment of the 4800-kw lithium heater design for future 300-kw system testing was tested in 2000°F lithium. The resistance of the alumina heater insulation, and the condition of the heater as a whole, remained good throughout the 500-hr test.

Architect-engineer work on modification of an existing building into a laboratory for housing the 100-kw loop and subsequent 4800-kw installation has been completed and construction will be completed in November.

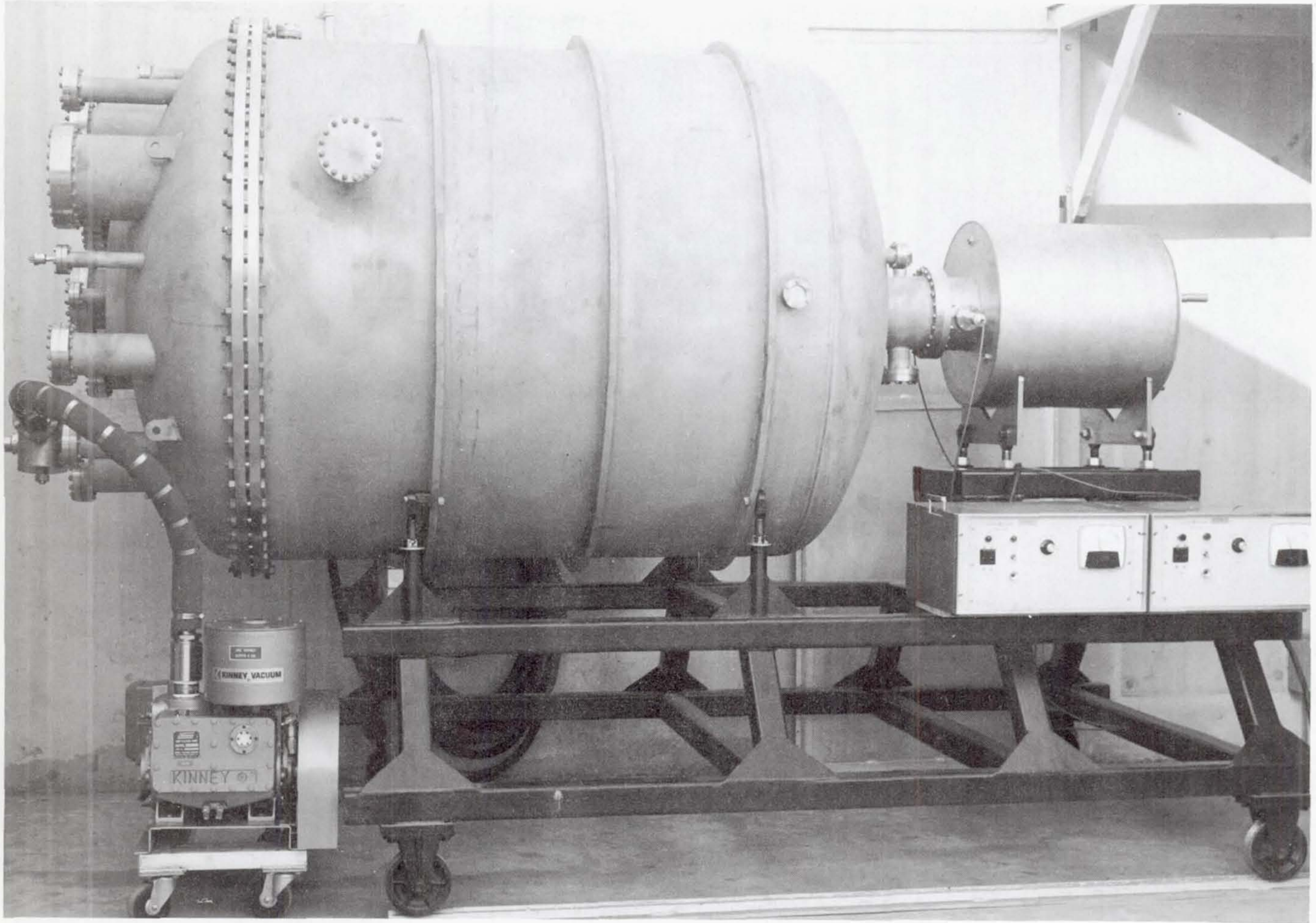


Fig. 4. Containment tank

Plans

During the next six months insulator-lithium compatibility tests will continue and a heater segment with BeO insulation will be tested. Preliminary erosion results will be obtained with the 250-ft/sec lithium loop. The 100-kw loop will be moved to the new laboratory for completion of fabrication. Overhaul of the 4800-kw MG set, and design of the foundation and building for the MG set, will be completed.

REFERENCES

1. Elliott, D., Cerini, D., Hays, L., and Weinberg, E., "Liquid MHD Power Conversion," SPS 37-31, Vol. IV, pp 186-191, Jet Propulsion Laboratory, Pasadena, California, February 28, 1965.

2. Elliott, D., Cerini, D., and Hays, L., "Liquid MHD Power Conversion," SPS 37-32, Vol. IV, pp 134-141, Jet Propulsion Laboratory, Pasadena, California, April 30, 1965.

3. Elliott, D., Cerini, D., Eddington, R., Hays, L., and Weinberg, E., "Liquid MHD Power Conversion," SPS 37-33, Vol. IV, Jet Propulsion Laboratory, Pasadena, California, June 30, 1965.

4. Elliott, D. G., "DC Liquid-Metal Magnetohydrodynamic Power Generation," Proceedings of Sixth Symposium on the Engineering Aspects of Magnetohydrodynamics, University of Pittsburgh, Pittsburgh, Pa., April 21-22, 1965.

Page Intentionally Left Blank

FISSION CELL RESEARCH
NASA Work Unit 120-27-06-06
JPL 320-70601-1-3280

This task terminated at the end of FY 1965. Final experiments with the large fission-electric cell were completed at the General Electric Nuclear Test Reactor; a maximum potential of 13,000 v was achieved. Post-irradiation examination of the cell and disposal of radioactive material were completed under Purchase Order NO. AL4-329218, now in administrative close-out phase. The associated experimental equipment was disassembled and reassigned to several groups at JPL. Two final technical reports on the experimental program, one covering the small capsule, the other the large capsule experiments, have been written and will be published. A final technical report covering fission-electric cell reactor system studies is now in preparation.

PUBLICATIONS

A report entitled The Two-Region Fission Electric Cell Reactor, by J. L. Shapiro, was published as JPL TR 32-685, dated February 15, 1965.

Page Intentionally Left Blank

NUCLEAR ROCKET
PROPULSION (122)

Page Intentionally Left Blank

ROCKET REACTOR RESEARCH (122-28)

REACTOR PHYSICS RESEARCH
NASA Work Unit 122-28-02-03
JPL 322-80301-1-3280

This task was terminated at the end of the fiscal year. During the report period, calculations were continued on the criticality effects of hot hydrogen propellant gas in an annular region between core and reflector of a gaseous core cavity reactor. These have included consideration of slowing-down of fast neutrons, rethermalization of slow neutrons, and contribution to temperature coefficient of reactivity due to the rethermalization process. The fast (Doppler) component of temperature coefficient has also been explored briefly.

Preliminary results in some of these areas were reported in "Neutron Rethermalization in Gas Core Reactors," J. L. Shapiro and C. J. Heindl, SPS 37-31, Vol. IV, February 28, 1965. Reports covering the results achieved since that time are now in draft form.

Page Intentionally Left Blank

SPACE POWER (123)

Page Intentionally Left Blank

ADVANCED CONCEPTS (123-06)

SOLAR POWER SYSTEM DEFINITION
NASA Work Unit 123-06-02-01
JPL 323-60101-2-3420

SOLAR THERMIONIC – SOLAR PHOTOVOLTAIC COMPARISON

Solar Thermionic power sources have been proposed as alternates or replacements for solar photovoltaic sources for various missions. As yet, little work has been done to compare, in an analytical manner, the two sources for specific missions. This study is intended to analytically investigate the tradeoffs and cross-over points of weight, area, and reliability between solar thermionic and solar photovoltaic power systems for the following four applications.

1. Solar and planetary probes over a Sun probe range of 0.3 1.7 astronomical units.

2. Earth orbiters for circular, equatorial orbits at altitudes of 500, 3,000, and 10,000 km.

3. Lunar, Mars, and Venus orbiters for eccentric orbits of 10- to 50-hr periods.

4. Lunar stations for daytime operation only.

For each application, a power range of 100 to 4,000 w will be investigated. Also, the state of the art for both devices will be extrapolated to 1977 in order to determine the future potential of each source.

Because of manpower limitations within the cognizant area, it was decided to have the work performed by a contractor. A competitive fixed price procurement was initiated and on April 7, 1965, a contract was obtained with EOS, Pasadena, California, to perform the study. The contract is for $58,401, and the work is scheduled to be completed within 6 mo.

The contract has been progressing in a satisfactory manner. Environmental conditions for the four applications mentioned above have been formulated, and estimates have been made of performance degradations due to environmental factors. Both the present and future performance capabilities of the two sources have been specified and system models have been defined. In addition, work is well along in the evaluation of stowage and packaging problems, attitude control requirements and interactions, system synthesis and sizing, and system failure mode analysis.

JPL has worked closely with the contractor in formulating information on both the present device capabilities and future device potentials. Close monitoring of the contractor will continue in order to obtain an optimum output from the study.

Page Intentionally Left Blank

20 WATT/LB PHOTOVOLTAIC SOLAR ARRAY
NASA Work Unit 123-06-03-01
JPL 323-60201-2-3420

OBJECTIVES

The objectives of this program are to evaluate the fabrication feasibility of a solar cell array to power an electric propulsion system for unmanned planetary exploration spacecraft missions anticipated in the next 5 to 10 yr. Two basic array power sizes are being considered in this program: A 3- to 10-kw array to power a spacecraft launched by an Atlas/Centaur booster and a 30- to 50-kw array to power a spacecraft launched by a Saturn I-B/Centaur booster. The solar array systems are based upon a specific power capability of 20-w/lb. Only materials and technologies which have been or can be developed within 1 yr from the initiation of this program are being considered.

DEVELOPMENT PROGRAM

In February 1965, a contract was placed with the Boeing Company, Seattle, Washington, for the 20-w/lb solar array feasibility program. The contract is a level-of-effort type not to exceed 5,500 man-hr. The total original funds committed were $115,000.

Since the initiation of this program, the interface coordination effort required to support the electric propulsion mission system study has significantly exceeded original estimates. Originally Boeing has proposed to support only one electric propulsion study and participate in a limited number of coordination meetings. The solar electric mission program has since evolved into an expanded effort with two separate studies being conducted by HAC and EOS, Inc. In order to have Boeing support the additional interface coordination and conduct the originally planned feasibility study, it was necessary to increase the total Boeing funding to $160,000.

The program milestones and schedules are shown in Fig. 1. Four mo of study have been completed on the 20-w/lb solar array feasibility program; selection of a baseline configuration and initiation of the preliminary design phase is impending.

PROGRAM ACHIEVEMENTS

Interface coordination meetings between Boeing and the two electric propulsion systems contractors have been held on a biweekly basis to discuss the problems and interfaces required to integrate the large solar arrays and the electric propulsion system. As a result of these interface coordination efforts, Boeing has generated a "Design and Criteria" document for the solar array preliminary design phase. The basic ground rules and system requirements are incorporated in this document.

At an early date in this program one of the most promising means of attaining the 30- to 50-kw requirements appeared to be a roll-up concept. One method of deployment of such a system would incorporate the stem system developed by de Havilland Aircraft Ltd., of Canada. In order to gain further basic design details and understand the stem system and its applications, a field trip was taken to de Havilland by Boeing and JPL. The complete analysis of the stem system is contained in Boeing Bimonthly Report No. 2.

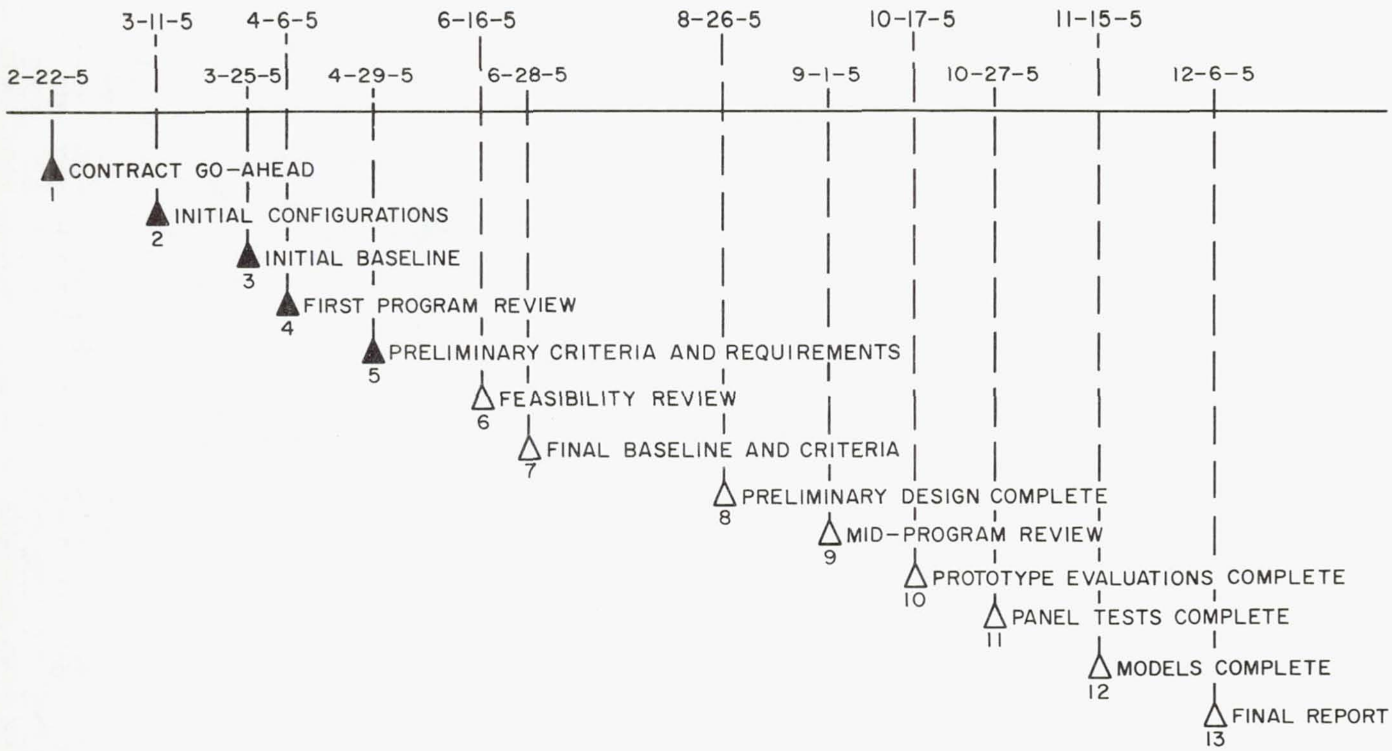


Fig. 1. Program milestones and schedules

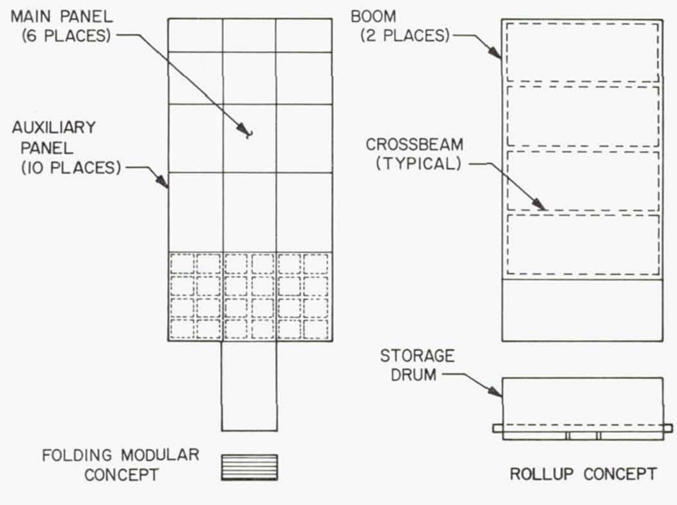


Fig. 2. Folding modular and rollup system

Boeing has several configuration concepts based mainly upon the Saturn I-B/ Centaur system, which has had priority in the mission study portion of the effort. Components, materials, weight, reliability, and state-of-the-art tradeoffs are in progress. To date, two basic configurations, the folding modular and the rollup system (Fig. 2) appear the most promising; however, the latter appears to offer a more difficult design to develop. Preliminary power-to-weight estimates ranging from 20 to 26 w/lb have resulted from analysis to date. Several types of deployment systems are being considered and evaluated for the mentioned parameters. Solar cell system-tradeoffs are being conducted as a function of thickness, coverglass system, dielectric alternates, thermal analysis, and power output. Indications are that the optimum solar cell system would incorporate a 2-4 mil coverglass, 8 mil thickness N/P solar cells, and Hr film or fiberglass tape mounting.

Two bimonthly reports designated the "20-W/lbs Solar Array Feasibility Study" have been released by Boeing and are available through JPL. The bimonthly reports contain detailed analysis and tradeoffs being conducted by Boeing to support this effort. The preliminary design phase, sample fabrication, and program completion are scheduled during the first half of FY 1966.

FUTURE ACTIVITIES

Future activities in support of extreme lightweight systems are anticipated as a result of the Boeing study effort. A logical follow-on of this program, pending preliminary design outcome, would be to fund Boeing to perform a final design of the array structure and mechanisms and then fabricate either a complete system, or a portion thereof. Technical meaning and budget considerations would determine the amount or size of this fabrication effort.

Page Intentionally Left Blank

SOLAR POWER GENERATION (123-33)

PHOTOVOLTAIC ENERGY CONVERSION
NASA Work Unit 123-33-01-01
JPL 323-30101-2-3420

In order to extend the usefulness of the Solar Photovoltaic Power Systems in space exploration, the development efforts in support of the SR/AD Photovoltaic Energy Conversion Program during FY 1965 have included thin silicon solar cell investigations, initiation of large area, lightweight, deployable solar array structure development, and solar cell standardization. Total FY 1965 expenditures to support the Photovoltaic Energy Conversion Program were $255,000.

LARGE AREA LIGHTWEIGHT ARRAY

A program was initiated in mid FY 1965 for the design and fabrication of large area, lightweight, deployable solar array structures. The requirements for the array development program were written without regard to a specific mission; however, the configuration is limited by specified launch envelopes and design constraints which are felt to be representative of a class of spacecraft missions. Basically these constraints are the use of the Atlas-Centaur Launch Vehicle with a Surveyor type shroud, an interplanetary probe mission, and chemical injection at encounter. The goal of this effort will be the fabrication of a 50-ft^2 prototype test element demonstrating a structural weight of 0.3 lb/ft^2, deployment and retraction systems, and reliability of the design concepts and a mastery of the technology involved.

In mid-May 1965, a contract was placed with Ryan Aeronautical Company, San Diego, California for a 56-wk structure development program. The program is a three-phase effort involving a total estimated cost of $134,000. The program has been split-funded to reflect expenditures of $83,000 in FY 1965 and $51,000 in FY 1966. Figure 1 shows the tentative schedule and milestones to meet the objectives of this effort.

Presently the program is at the mid-point of the Phase 1 development effort. During the first four weeks of this effort extensive layout, structural analysis, test sample fabrication, and materials investigation have been in process to optimize the beam sections with regard to load carrying ability, foldability, weight, width, substrate attachment differential growth, wire routing provisions, drive system, and cross section stiffners. The analysis is being supported by laboratory testing where necessary. The Phase 1 effort will continue for an additional four weeks for selective evaluation of the structural, thermal, dynamic, and reliability characteristics of the various investigations being conducted to support the Phase II design effort.

The Phase II and Phase III efforts of this program will continue into FY 1966; estimated completion of the program is during the fourth quarter of FY 1966. Tentative plans reflect additional support of FY 1966 funds to incorporate an environmental test program and dynamic analysis of the completed array. This effort is tentatively scheduled for initiation during the FY 1966 second quarter.

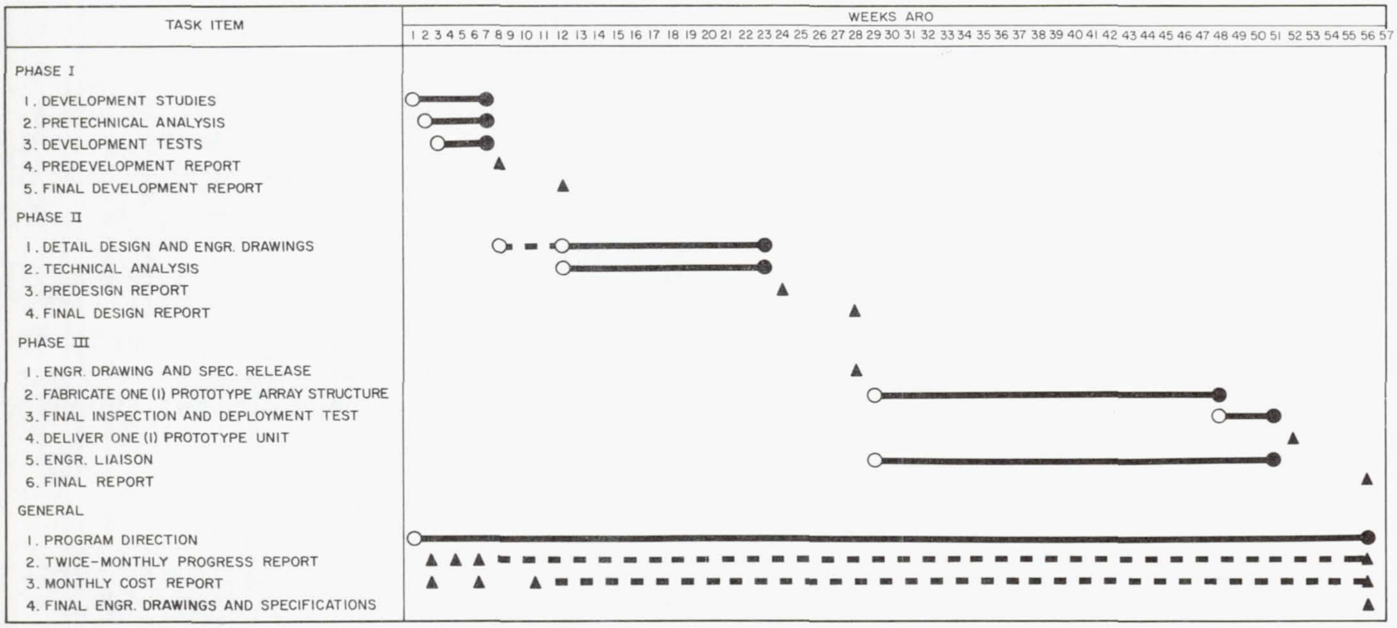


Fig. 1. Program major milestone chart and schedule

THIN CELL DEVELOPMENT PROGRAM

An in-house effort to investigate the feasibility and to electrically and mechanically evaluate thin single-crystal silicon N/P solar cells was initiated in the first quarter of FY 1965. The investigations have included electrical, mechanical, interconnection materials, and lightweight module assembly development and evaluation. Total funds expended to support this effort were \$115,000. This includes fixed price orders to Heliotek (\$25,000), RCA (\$5,000), and Texas Instruments (\$10,000) for thin cell development and hardware delivery. The remainder of the total was used for test facilities procurements. This includes procurement of a thermal equilibrium test chamber (cell thermal investigations), universal materials tester (mechanical investigations), resistivity measurements tester, and tungsten light system for electrical measurements.

The electrical parameters of 0.008-in.-thick single crystal silicon N/P solar cells have been measured as a function of temperature and intensity between the ranges of -10 to 60°C and 30 to 180 mw/cm^2. The evaluations to date reflect that the 0.008-in. solar cell exhibits similar electrical characteristics to the more common 0.012- to 0.018-in.-thick solar cell and can be competitively utilized as a power source over the same ranges of temperature and intensity. Although the w/ft^2 are less in the 0.008-in.-thick cell, significant advantages can be gained in w/lb when integrated with lightweight structure systems. Results of the electrical parameter investigations have been reported in JPL SPS No. 37-31, Vol. IV.

Electrical parameter investigations are continuing in FY 1966; these will include the "wrap-around" type thin cell and cells down to 0.004-in. thickness.

BUS BAR MATERIALS INVESTIGATIONS

In conjunction with the thin-cell investigation, evaluation and development of various bus bar materials and configurations have been in progress to optimize the electrical-mechanical interface of the solar cell submodule for flexibility, thermal conduction, and solderability. Materials such as silver, copper, molybdenum, titanium, tungsten, kovar, danalloy, palladium, niobium, and gold have been evaluated in this program. Samples have been subjected to various thermal shock tests, thermal cycling, flexure tests (Fig. 2) and contact strength tests (Fig. 3). Test results to date indicate all the materials investigated can be used for solar cell interconnection with specific thermal and soldering constraints. The material that allows the broadest of these constraints has been found to be tungsten when utilized with a special plating. A comparison of thermal coefficient of expansion of materials investigated is shown in Fig. 4.

In addition to the materials investigations several bus bar configurations have been developed and integrated into solar cell matrices utilizing the results from the materials investigation. Several solar cell matrices have been fabricated using various thin film type substrates such as H-film mylar and silicon impregnated dacron cloth. The film substrate systems as shown in Fig. 5, 6, and 7, reflect H-film type substrates and two different types of bus bar configurations. Each configuration possesses varying degrees of versatility and flexibility. The thin film solar cell systems have exhibited power densities of 20-50 w/lb and are scheduled for environmental tests. The work on the lightweight film substrate has just been initiated in the 4th quarter of FY 1965 and is planned to continue throughout FY 1966. The FY 1966 efforts will be devoted to fabrication and development of sample deployable solar array assemblies, soldering techniques, and environmental testing to prove techniques.

SOLAR CELL STANDARDIZATION

The development of photovoltaic standards by high altitude balloon techniques and terrestial comparison methods is a continuing effort for which the total expenditures for FY 1965 were $53, 000.

The terrestial method developed by JPL in 1964 provided 15 calibrated secondary standards for distribution among NASA organizations. The efforts in FY 1965 included the procurement of 20 additional standards and calibration thereof.

The calibration of the 20 standard cells was completed in late February 1965. The calibration data provided correlation with the previously developed terrestial standards. The results will be tabulated and reported as an addendum to JPL Technical Report 32-634, <u>Development of Photovoltaic Cells for NASA</u>.

A contract to Litton Industries for the amount of $30, 000 to conduct high altitude balloon flights for solar cell calibration has been placed. The contracted effort to Litton is for balloon hardware and flight operations. The schedule reflects four balloon flights at a float altitude of 80, 000 ft. for 4 hr each flight.

The objectives of the FY 1966 program are: (1) calibration of broad spectrum silicon solar cells, (2) correlation of all previous flights, (3) generation of standards for Web Dendrites (USAF coordination), (4) development of a narrow band pass filter system, and (5) measurement of "sky radiation effects."

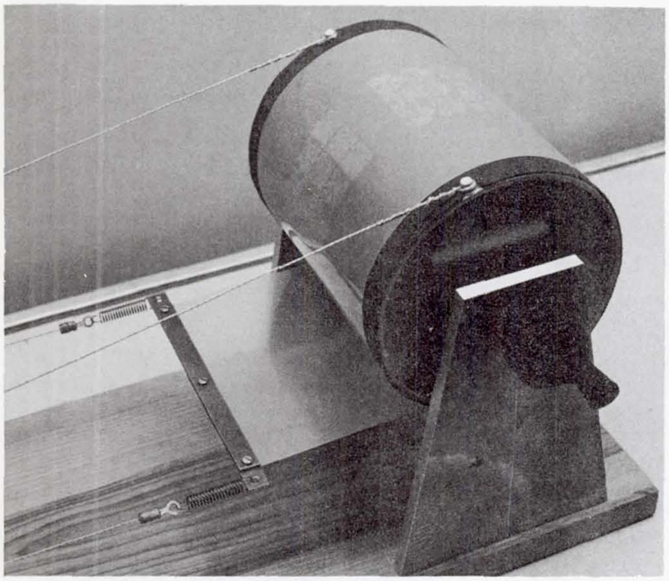


Fig. 2. Solar cell contact flexure test apparatus

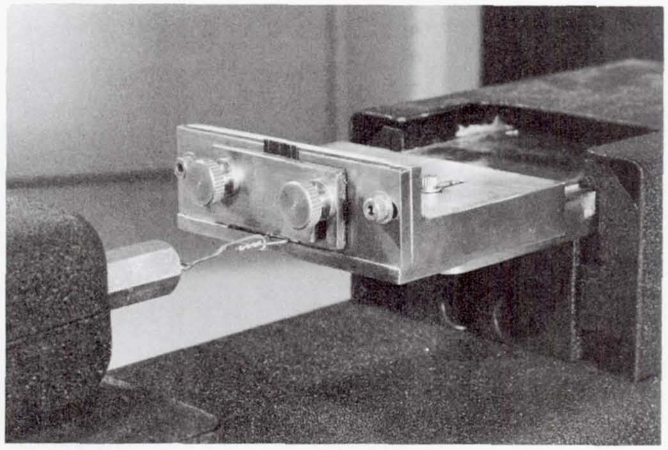


Fig. 3. Solar cell contact strength test apparatus

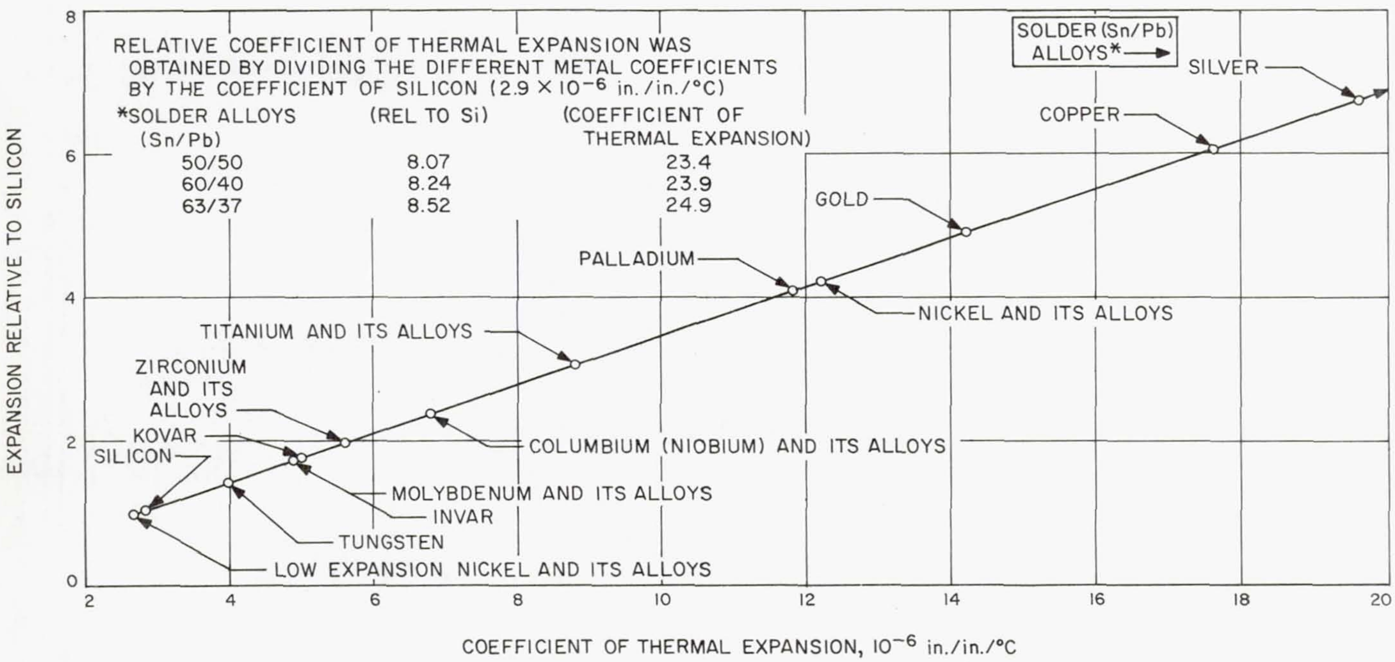


Fig. 4. Coefficient of thermal expansion of metals relative to silicon

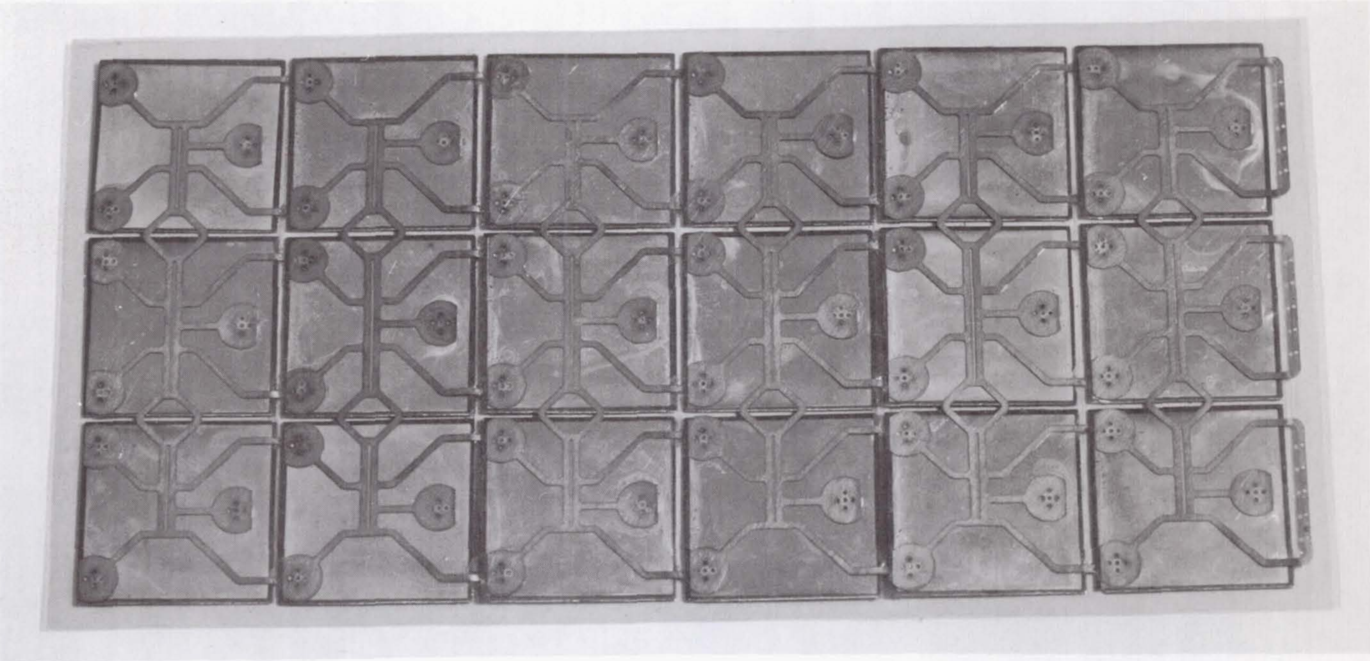


Fig. 5. Thin film solar cell matrices – 0.008 in. silicon cells, 0.003 in. H-film

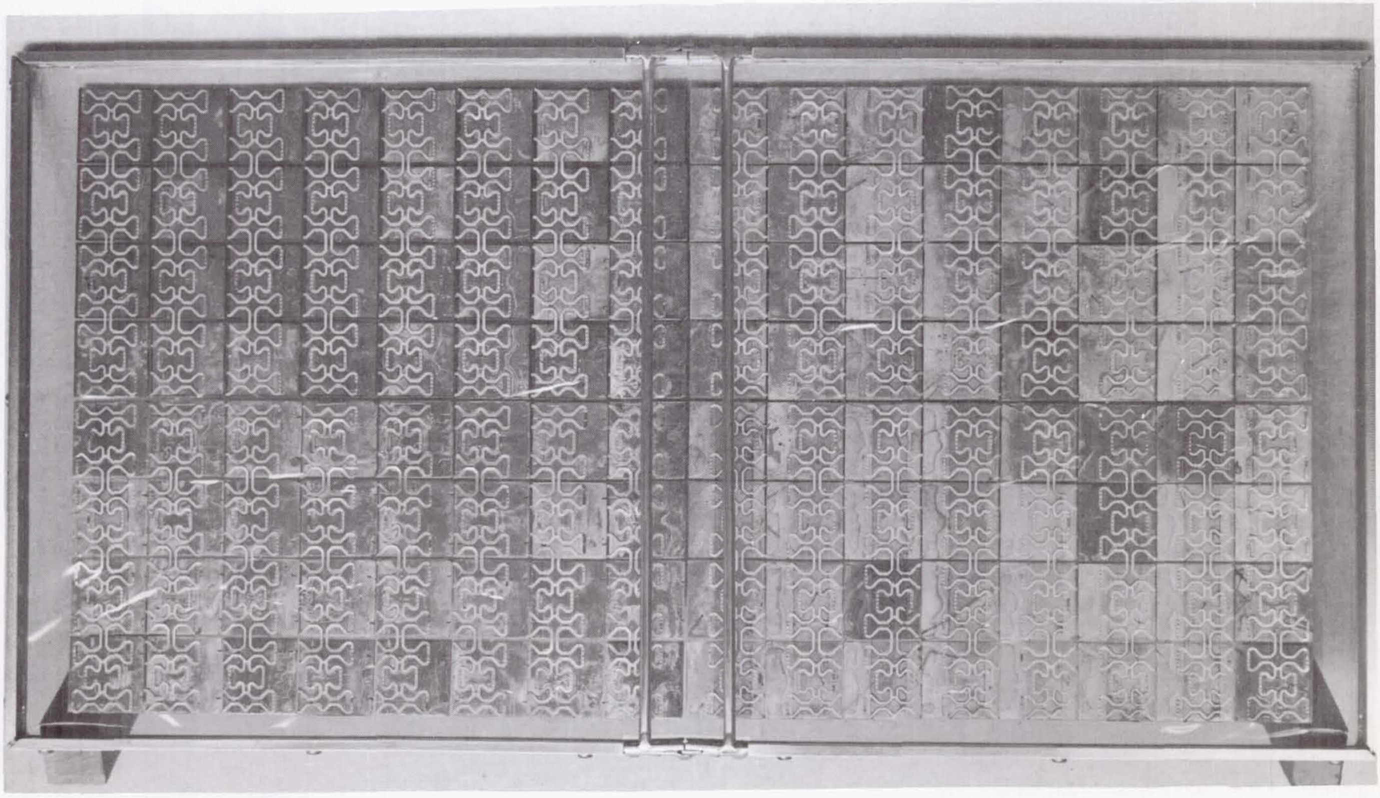


Fig. 6. Thin film solar cell matrices – bus bar (front view)

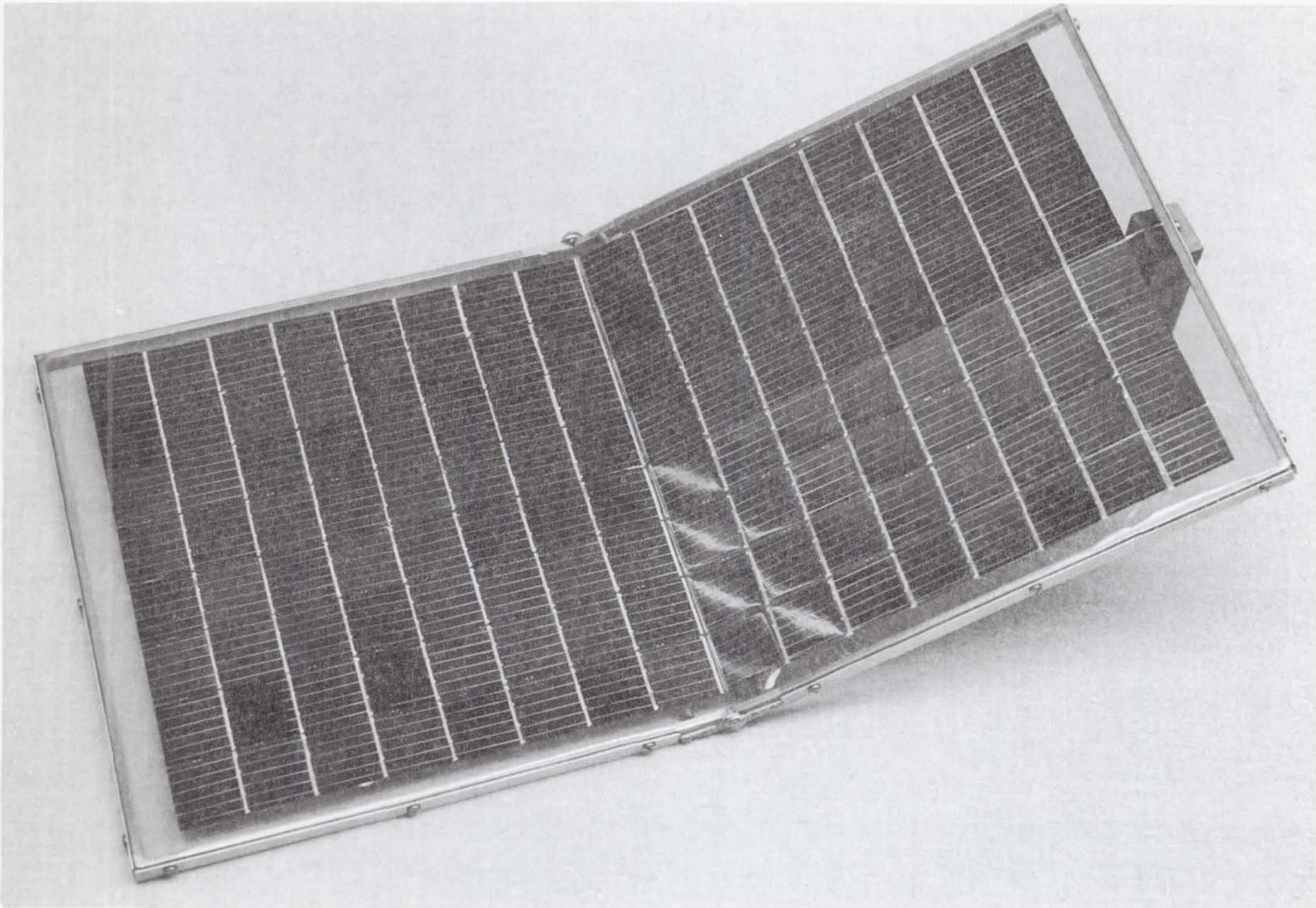


Fig. 7. Thin film solar cell matrices – bus bar (rear view)

The fabrication of ground support equipment has been completed. The GSE (Fig. 8) has been utilized in ground environmental test of the tracker system and provides calibration voltages of 0.05% for the functional operation of the FM Telemetry System. Terrestial calibration of all four flight systems has been completed and equipment is in preparation to be shipped to Litton. The flight operations efforts will continue through the first quarter of FY 1966.

An Optical Coating Laboratories solar simulator was procured for $20,000 in support of solar cell standardization. It was hoped that correlation of the high altitude balloon standard with the solar simulator could provide an accurate means of calibrating the solar simulator using balloon calibrated solar cells and broad spectrum solar cells. Due to lack of manpower the installation and check out of the OCLI simulator have not been accomplished. It is planned that this effort will be conducted in FY 1966.

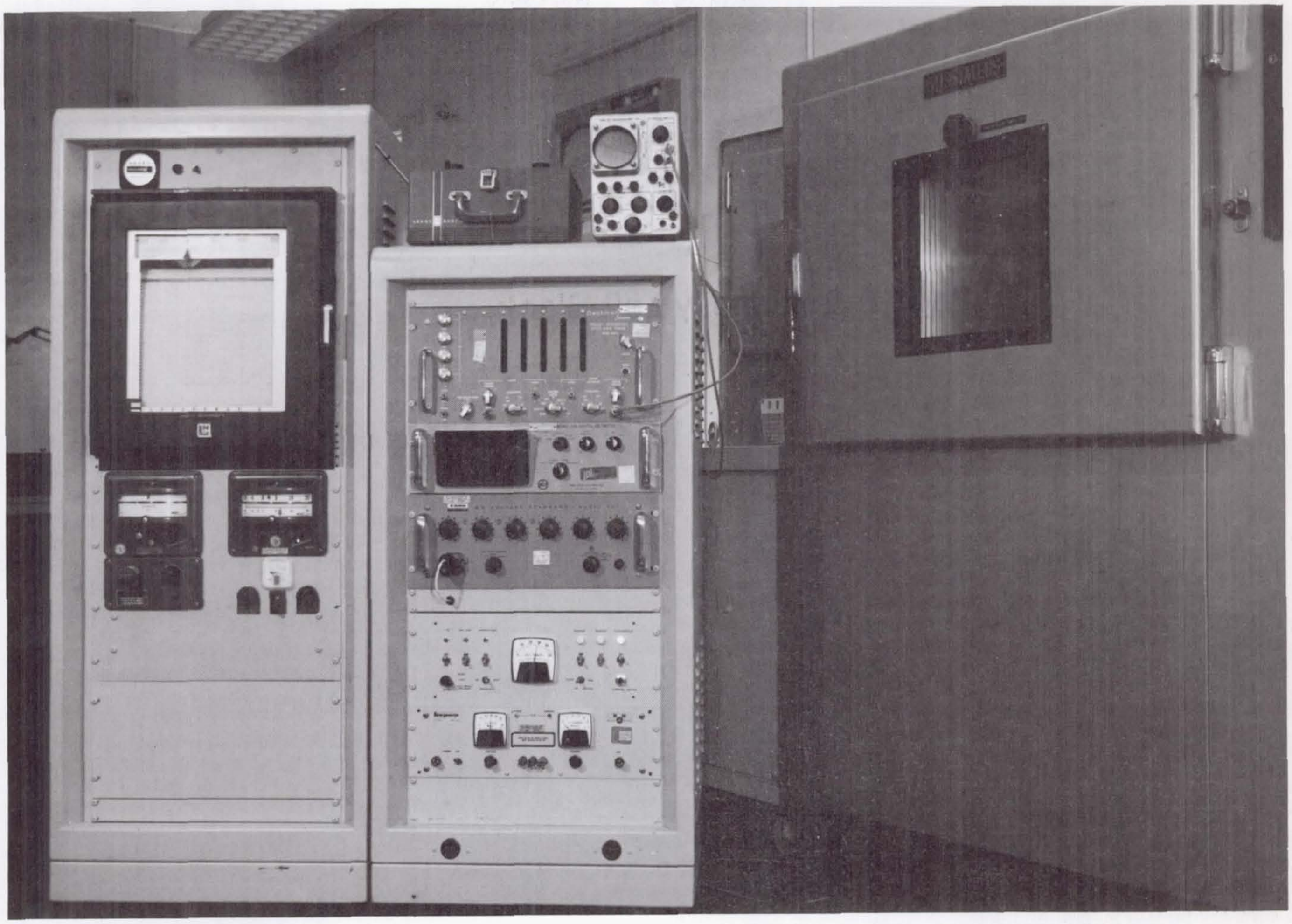


Fig. 8. Balloon flight calibration ground support and checkout system

Page Intentionally Left Blank

SET CONVERTER AND GENERATOR DEVELOPMENT
NASA Work Unit 123-33-02-01
JPL 323-30201-2-3420

The development of solar heated thermionic converters and generators was initiated at JPL under NASA sponsorship in FY 1962. The effort was continued and expanded as a consequence of the promising rate of progress observed. Progress is summarized in Table 1, showing the improvement in performance of thermionic converters.

Table 1. Thermionic converters performance progress

Parameter	FY 1962	FY 1965
Power output (at 1700°C), w/cm^2	12	44
Measured efficiency, %	3	12.5
Maximum life test, hr	119	7600 +
Environmental tests	none	20 g (0-2000 cps) 3-axis
		100 g (0.5 msec)

The converters built under this effort are of the planar electrode configuration with an interelectrode spacing ranging between 0.001 and 0.003 in. Such spacings are obtained by differential expansion of the electrodes at operating temperatures (2000°K emitter and 950°K collector). Typical configurations are presented in Fig. 1. The present converters weigh approximately 360 gm and deliver 50 electrical w, or a specific power of 15 lb/Kw.

Several such converters assembled in a supporting structure form a thermionic generator. In the solar heated thermionic generator the outer emitter faces of the converters, which are serrated to increase their absorptivity, form the cavity into which the solar energy, concentrated by a parabolic mirror, impinges.

Out of such generators tested in this country 4 had been tested at JPL under this program. Also, a fifth monoconverter solar thermionic generator was assembled and tested. This generator was designed to operate in Earth atmosphere without the usual vacuum environmental protection.

The progress achieved at JPL on the solar thermionic generator development is summarized in Table 2, showing the performance of 2 five-converter thermionic solar generators.

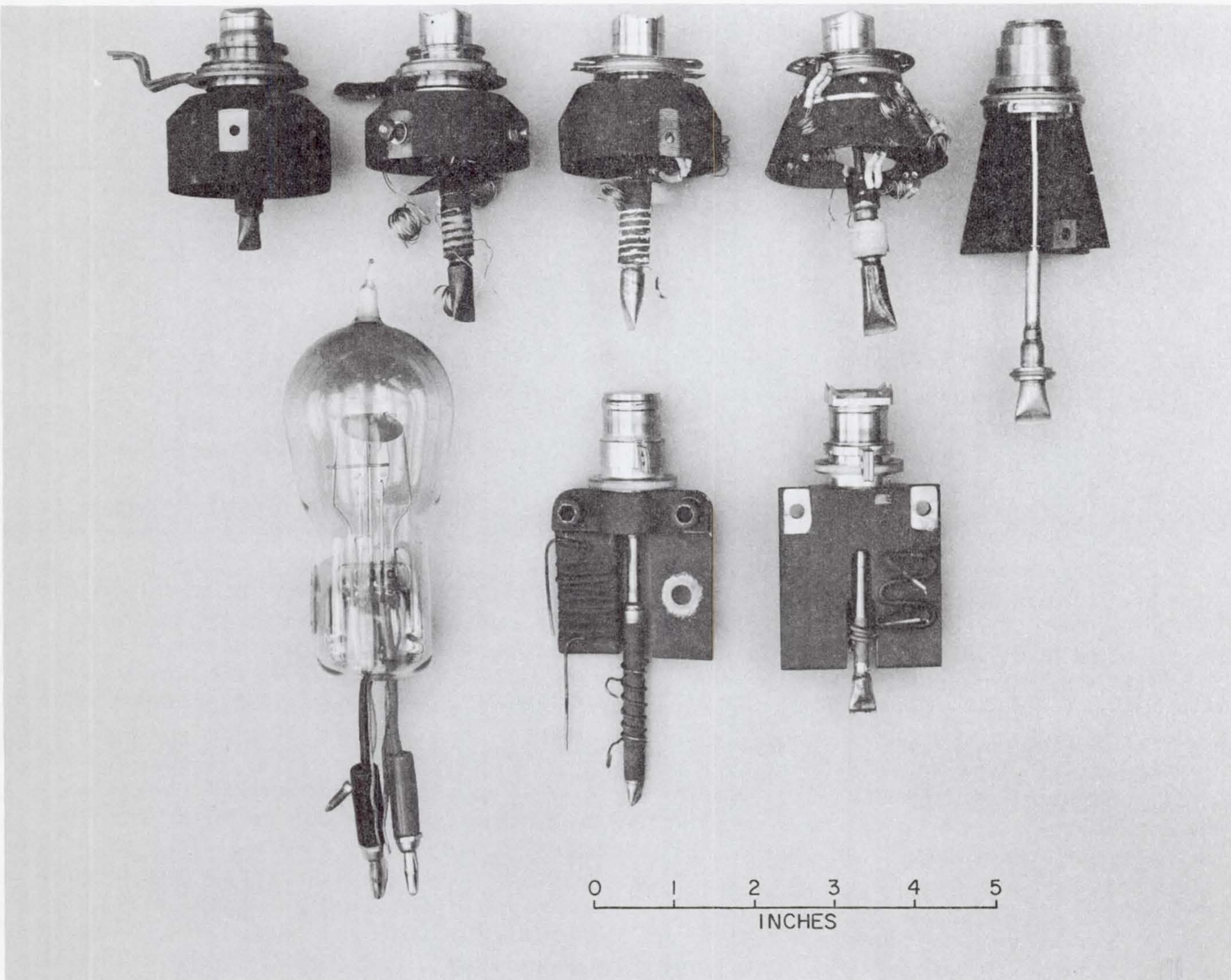


Fig. 1. Converter configurations

Table 2. Five-converter thermionic generator performance progress

Years (FY)	1962	1965
Generator power output, watts	41	150
Measured generator efficiency, %	3.1	10.5

Further improvements as a result of broader experience and better understanding of the fundamental laws of thermionic energy conversion are expected from the programs now underway or planned for the near future. Generators with large power outputs and higher efficiency are now in design stages as a result of the experience acquired in the past.

THERMIONIC CONVERTER DEVELOPMENT

Electro-Optical Systems

Under this part of the effort contract (650699), Task B for $78,480 was initiated with Electro-Optical Systems in September 1964. The purpose of this contract was to design and build advanced thermionic converters and generators. The conceptual design of EOS thermionic converter presents several interesting features: (1) An integral collector radiator to improve the heat transfer characteristics and to avoid possible troubles at the braze interface between collector and radiator, (2) A compact packaging of the converter with a flat radiator, and (3) A sturdier and more environmental-resistant construction. Figure 2 presents the sectional view of such a converter.

Under the present task several parameters were changed in the converters to improve their performance: (1) interelectrode spacing, (2) collector and emitter work function, and (3) heat rejection mechanism. The emitter area was reduced from 2.5 to 1.85 cm^2 and different materials were used as emitter and collector. Also, a new assembly technique was employed to obtain a closer interelectrode spacing. In the later engineering models, rhenium, both in vacuum deposited and in solid form, was used for both collectors and emitters, and the interelectrode spacing was reduced to approximately 0.0015 to 0.0025 in. These changes resulted in a 25% improvement in converter output performance with the output power density increasing from 13 to 16.4 w/cm^2. The results of this work were reported in the SPS 37-32, Vol. IV.

Future Plans. The previously described effort has been followed by a new contract (951225) with Electro-Optical Systems for $220,000. This contract, issued in March 1965, is divided into two major tasks: (1) to ascertain the performance of various electrode materials at different emitter, collector, and cesium reservoir temperatures and for different interelectrode spacings, (2) to study analytically and experimentally various converter geometries aided by the fabrication and tests of six engineering models of thermionic converters.

The electrode material evaluation will be performed in a test vehicle with easily interchangeable electrode materials. Included in the combinations of

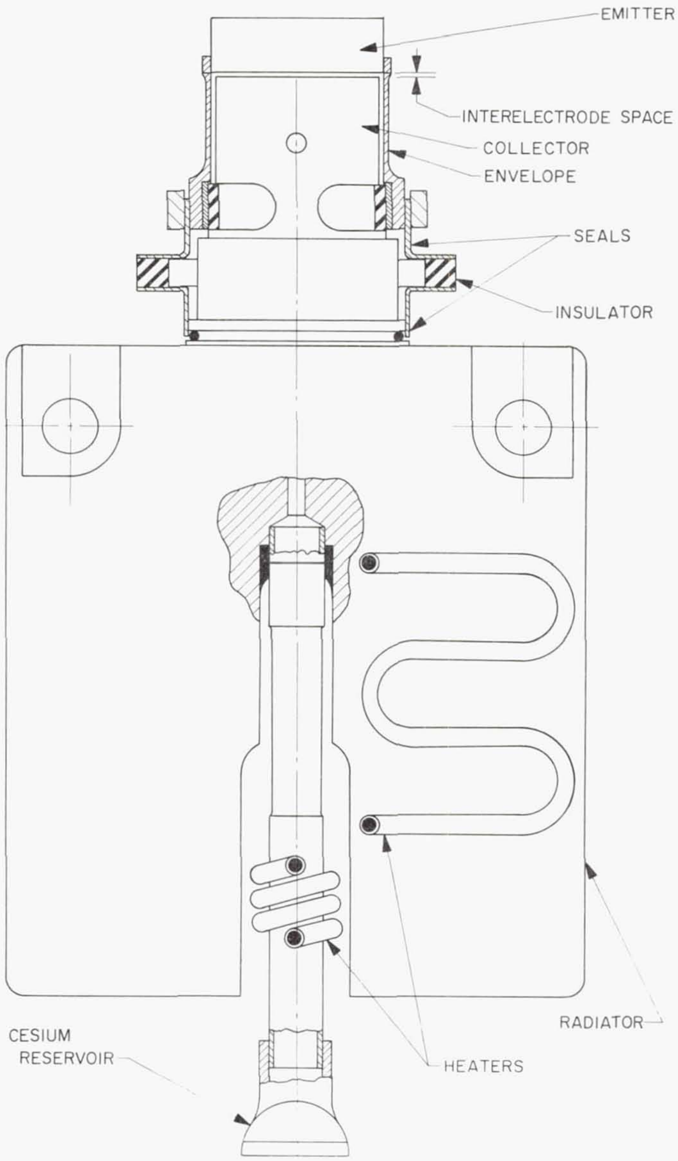


Fig. 2. EOS converter

materials to be studied are tantalum-tantalum, rhenium-rhenium, and rhenium molybdenum.

The converter study program includes: collector heat transfer, radiator heat rejection, ceramic to metal seal, interelectrode spacing, high temperature brazing, and rhenium electron-beam welding techniques. The contractor is currently in the design phase of the test vehicle and initial converter heat transfer study program.

Thermo-Electron Engineering Corporation

The effort under Contract 950671 with Thermo-Electron Engineering in Waltham, Massachusetts, was continued. This contract, initiated in FY 1964, is divided into several tasks, each with independent goals. Task I, funded to a level

of $250,812 was initiated in October 1963. This task covers the design and fabrication of improved models of thermionic converters and their assembly into a four-converter generator. The goal is a generator capable of producing 175 electrical watts with a minimum efficiency of 10%. Under this task converters with a power output density of 22 w/cm^2 of emitter area at 1700°C emitter temperature were obtained. At 1800°C emitter temperature the same converters demonstrated a maximum power output density of 28.5 w/cm^2. The weight of the finalized version of the engineering model was 256 gm for a converter capable of delivering 57 w output at 0.7 v. Such converters (Fig. 3) were successfully tested at the environmental requirement for an Atlas-Agena (20g sinusoidal frequency vibration up to 2000 cps in 3 orthogonal axes and accelerations up to 100 g for 0.5 msec). All converters operated successfully after tests without signs of performance degradation.

A four-converter generator was assembled and tested at the contractor's facilities. Preliminary results were 114-w output with 11.2% conversion efficiency at an estimated emitter temperature of 1650°C. During successive tests the generator was damaged as a consequence of an electron-bombardment runoff and is presently being repaired. Under similar conditions a five-converter generator tested in 1964 produced 84 w at 7.5% efficiency. The increase in performance of the four-converter generator is attributed to improvements in individual converter performance, improvements in generator design and shielding techniques, and reduction in thermal stray conduction losses.

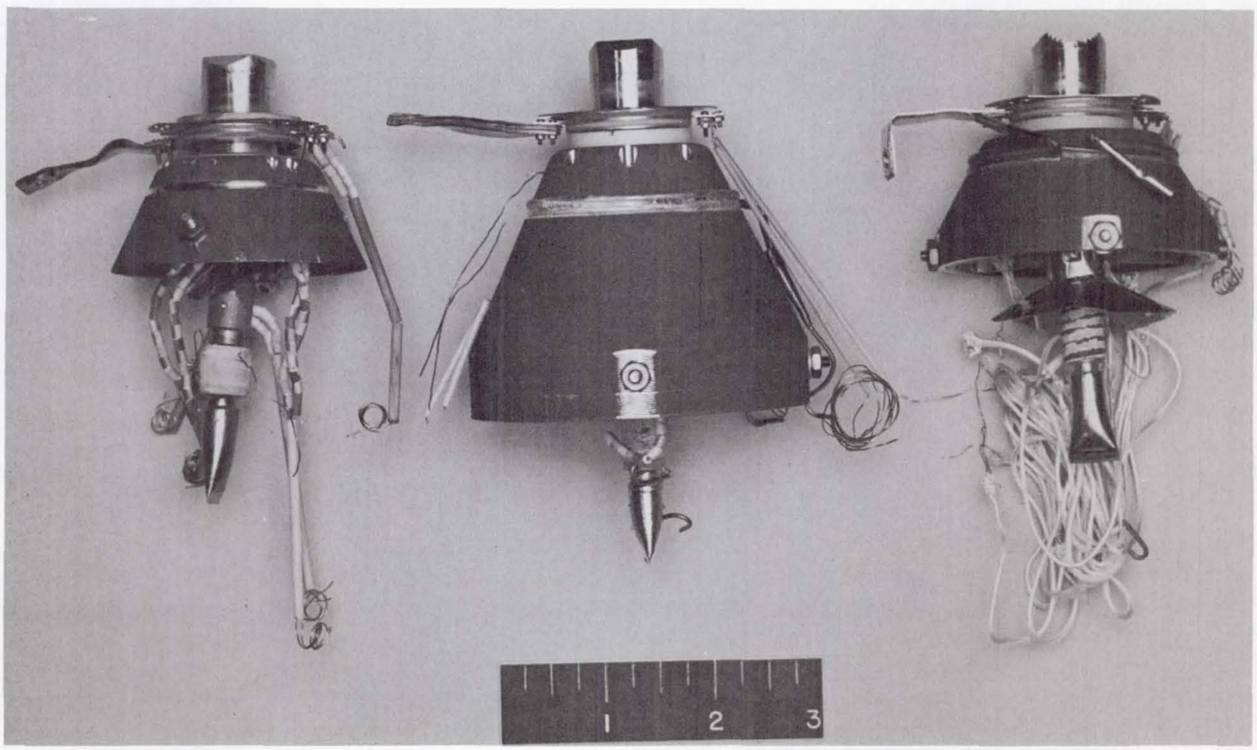


Fig. 3. Improved model converter

Task II of Contract 950671, funded for $64,980, was also initiated in October 1963. It was successfully concluded in February 1965. The goal of this task was to develop an advanced version of a thermionic converter with improvements in several areas: (1) a novel concept of a concentric metal-to-ceramic seal with improved protection from accidental shocks and thermal overexposures, (2) reinforced convoluted emitter support, (3) improved power lead attachment, (4) reduction in packaging size with inclusion in a small central angle, and (5) improvement in performance and efficiency.

Such goals were successfully achieved with the final version of the converter, weighing 330 grams, encompassed in a 30-deg central angle. The previous converters occupied a 60-deg angle. Figure 4 presents a sectional view of the final structure; a comparison of the previous and newer model can be readily made. The final version demonstrated a 12% efficiency at a higher voltage output than previously observed. The prototypes also successfully passed environmental tests at the Atlas-Agena levels.

A final report (TE 34-65) was issued for this task.

Task III of Contract 950671 for $71,300 was initiated in October 1963. The goal of this effort was the investigation of rhenium as emitter material. Several surfaces made of bulk material and pyrolytically vapor-deposited rhenium were investigated. Different methods of surface preparation and material thermal treatments were used for each type of sample. The surfaces were prepared by electropolish, electroetch, and mechanical abrasion. The investigation tools used in this task were the thermionic scanner and the variable spacing test vehicle, both developed under a previous JPL contract (950228) with Thermo-Electron Engineering Corporation (TEECO). The influence of the thermal treatment of the emitter material at different time-temperature conditions was also to be investigated. Under previous efforts it was indicated that such treatment resulted in improved thermionic properties. The results of this task demonstrated that the bulk material was better than the pyrolytically deposited one, despite the stronger preferred crystal orientation of the latter. Also, it indicated that for both types of material an electroetched surface finish results in better emitters than those produced by electropolishing or mechanical abrasion. It was also demonstrated that the pyrolytic vapor deposition of rhenium on tantalum was not sufficiently developed to produce reliable adherence and contaminant-free material (40 ppm for bulk material, 300 ppm for vapor deposition). The thermal treatment of emitter material at temperatures up to 80% of the melting point for a long period of time improved the thermionic properties by promoting a more homogeneous surface and by exposing a preferred crystal orientation, which grows at the expense of other crystal planes and orients itself to present the lowest surface free energy. (This phenomena has been reported by Langmuir in 1924.) The results of this effort are summarized in Fig. 5.

Future Efforts. As a continuation of Task I of Contract 950671, a fixed-price purchase order for 20 converters was placed under Purchase Order AES-310910 with Thermo-Electron Engineering Corporation for an amount of $79,000. As a consequence of the damage sustained by the four-converter generator (built under Task I) during testing the converters used in this generator have had to be replaced. Since the converters developed under Task I of Contract 950671 demonstrated a high performance, a fixed-price order was negotiated to acquire 20 of these converters. These are intended for the following use:

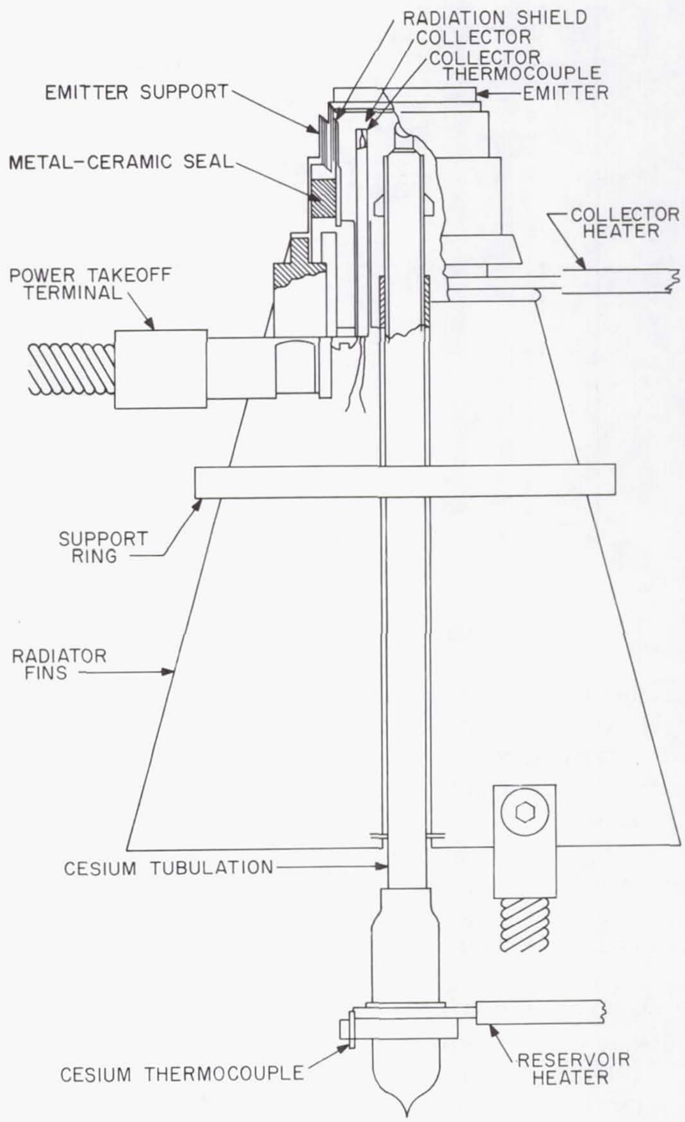


Fig. 4. Advanced thermionic converter design

Four to replace the ones damaged in the generator.

Two spares for same.

Four for long term life test to acquire statistical data.

Six for use in a six-converter generator.

Four spares for same.

The converters are to be procured to a minimum acceptance level of performance of 17 w/cm^2 power density at 0.6-v output and 1735°C "connected" emitter temperature, corresponding to 2000°K emitter surface temperature.

The fixed price purchase order is at present in final negotiations.

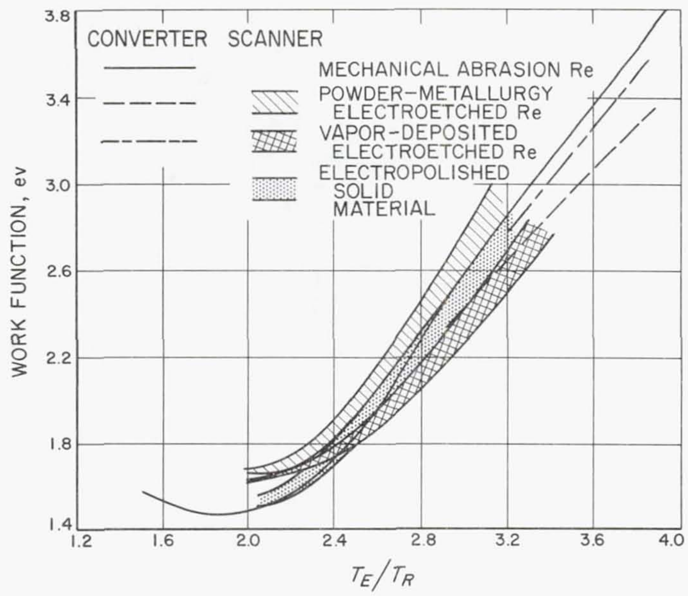


Fig. 5. Work function data for various rhenium surfaces

Two other purchase orders will cover the acquisition of two converters from EOS and two from TEECO. These converters, to be supplied without additional heaters on the cesium reservoir, will be used in experimental demonstration of the cesium reservoir temperature controls. The converters to be acquired under this fixed-price procurement will be similar to the regular production of both companies, and the cesium control will be obtained by special attachments to be developed under a separate cesium reservoir temperature control program.

ADVANCED GENERATOR DESIGN

A fixed-price contract (951230) for $12, 750 was initiated in May 1965 with Thermo-Electron Engineering Corporation for the design of an advanced six-converter solar thermionic generator. The effort is to take advantage of experience gained in the tests of previous generators, the high performance of the converters developed under Task I of Contract 950671, and the design experience obtained during the design of the last four-converter generator. The goal of the contract is to produce a design of a generator capable of delivering 200 to 250 w at better than 10% conversion efficiency. The design will include: (1) thermal analysis of the cavity for different levels of heat input, (2) selection of the optimum geometry, (3) incorporation of improved thermal shielding, (4) environmental test of a mock-up generator, and (5) delivery of engineering drawings and calculations to document the generator design.

A $47, 639 cost-incentive contract (950858) was awarded to TEECO in April 1964 for the design, assembly, and acceptance test of a monoconverter generator to be operated in Earth atmosphere without the usual vacuum environmental protection. A schematic of the generator is presented in Fig. 6. The generator operated from a 30-in. -diameter solar concentrator which was obtained by mechanically forming an aluminum disk. The generator and the mirror were mechanically elevated to the proper solar declination angle. Solar tracking was performed by a synchronous electrical clock movement. The generator was assembled and solar tested; the maximum performance was 21-w output at 0. 6 v with an efficiency of 5. 5%. After

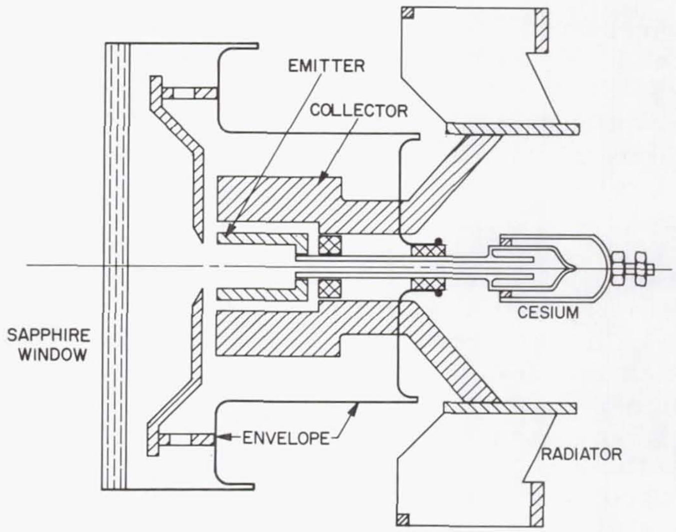


Fig. 6. Modular solar converter generator design

32 hr of testing the generator failed due to a crack in the sapphire window. The defect was probably due to high stress induced by an excessive concentration of the solar energy, aggravated by a metallic deposit on the inner side of the sapphire plate.

A paper presented by TEECO at the Solar Energy Society Conference at Phoenix, Arizona, March 15-17, 1965 summarizes the effort.

Future Planning

In order to demonstrate the feasibility of large power output from solar thermionics a program is being initiated for the design of a multi-converter generator. Such a generator, composed of 12 to 18 converters of the advanced design, will be capable of delivering 800 to 1000 w output in cislunar space. The thermal energy is to be supplied by a 9.5-ft-diameter mirror.

The design effort is directed toward obtaining a design to be demonstrated on Earth. It will consider optimum cavity aperture and generator thermal balance, mechanical assembly procedures, and problems of interference and thermal distortion. The program will result in a set of engineering drawings and will include the testing of a generator mockup, both from the standpoint of environmental resistance and to ascertain possible interferences. Improved and more efficient thermal shielding of the cavity is to be demonstrated.

Converters will also be procured to evaluate the use of a "heat pipe" as a collector heat removing means, materials compatible with electronegative elements such as cesium halides, and to demonstrate the feasibility of converters without a cesium reservoir.

IN-HOUSE EFFORTS

Parametric Tests of Individual Thermionic Converters

Each converter received from the manufacturer is parametrically tested at emitter temperatures of 1600, 1700 and 1800°C for various voltages and cesium reservoir temperatures. The voltage output is tested from 0.4 to 1.2 v in increments of 0.2 v and for each voltage value the cesium temperature is varied ±30°C on each side of the optimum in increments of 5 to 10°C. The test data is recorded both in a steady state condition after a thermal stabilization of 20 min at each selected value and by dynamic testing.

Efforts are pursued to define the proper emitter temperature measurement technique by optic pyrometry with experiments on hohlraums with different length-to-diameter ratios, obtained by different drilling techniques. Also, systematic observations are performed on the influence of contaminant deposition on the walls of the test chamber, its influence on the glass transmissivity and the consequent measured temperature errors. It was observed that not only the length-to-diameter ratio of black-body holes has influence on the recorded temperatures but that the sharpness and shape of the drill used could also result in large errors. The presence of "filaments" on the walls of the black-body holes (probably the result of material crystals displaced from their location during the drilling operation) also add to possible errors.

The converters are also tested for life under continuous operation at high emitter temperatures and normal power output. Five life test stations (Fig. 7) are in operation, the converters being heated by electron bombardment. The tests are interrupted for normal service maintenance. Up to the present time the longest operational time observed is 7600 hr; the tests are still continuing. It is planned that five more test stations will be operating in the third quarter of FY 1966 to permit accumulation of meaningful statistical data on the mean rate of failure of thermionic converters.

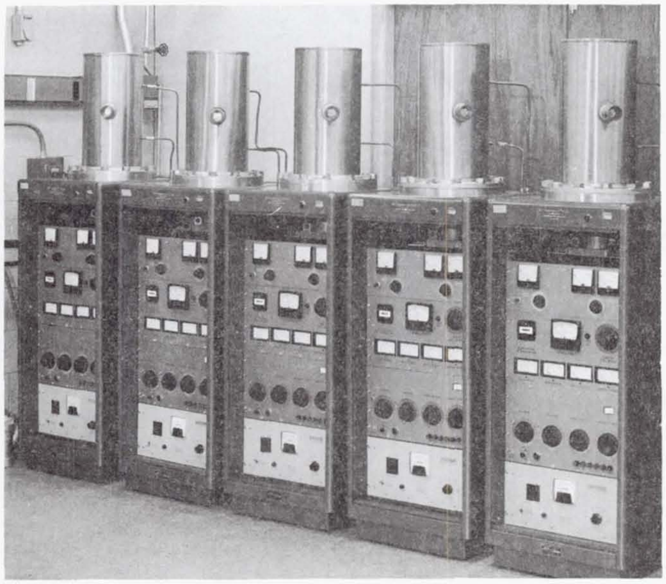


Fig. 7. Converter life test stations

A thermionic generator composed of three converters was tested in the laboratory using electron bombardment. The tests were performed at 4 levels of power input from 700 to 1100 w. The maximum power output observed was 57 w. The generator is scheduled for solar tests, using concentrated solar energy, at the solar thermionic test site.

Advanced test techniques involving electrode work functions and cesium conduction in thermionic converters are in the process of development and application. These will be included in the test procedures for converter evaluation to permit a better diagnosis of the observed converter performance.

In order to try to evaluate the interelectrode spacing and its effects on the converter performance a gammagraphic technique is being implemented. A 10 curie iridium 192 source was obtained and will be used to produce shadow gammagraphics. It is expected that spaces of 0.001 in. will be resolved.

It is planned that the laboratory in-house effort will be expanded to include: (1) high temperature metal-to-ceramic seal investigation including alumina, hafnia, yttria and metals such as niobium, tungsten, and rhenium; (2) high temperature brazing and materials-compatibility evaluation. It is expected that such effort will result in an insight into the difficulties experienced in these regions.

A paper was presented at the Solar Energy Society conference in Phoenix, Arizona, March 15-17, 1965, covering the test results of the evaluation of a solar metal concentrator and a thermionic generator. The paper was titled Performance Testing of a Solar Electrical Thermionic Generator System.

Two papers have been prepared to be presented at the International Thermionic Conference, London, England, covering the test results of five thermionic generators and the observations resulting from the tests of 80 thermionic converters of different origin.

Page Intentionally Left Blank

THERMIONICS SUPPORTING RESEARCH
NASA Work Unit 123-33-02-02
JPL 323-30601-2-3420

OBJECTIVES

To aid in the more efficient development of thermionic power conversion, a research effort was initiated at JPL in 1964 under NASA sponsorship. The basic objectives of this supporting research program are:

1. Obtaining reliable thermionic converter operation design data.

2. Better understanding of the conversion process so that the interaction of various parameters may be predicted in advance of converter or generator design.

3. Developing new materials and techniques to improve converter electrical performance and reliability.

GENERAL APPROACH

The FY 1965 effort of supporting research investigated four different areas of interest:

1. Test vehicle fabrication and instrumentation.

2. Rhenium-molybdenum performance evaluation in the presence of cesium vapor.

3. Preliminary performance evaluation of tungsten-molybdenum in the presence of cesium-floride and cesium vapor.

4. Development of an analytical model to describe the conversion process.

This effort was performed by Thermo Electron Engineering Corporation (TEECO) under Contract 950671, Task IV. The contract period extended for one full year, June 1964 to June 1965, and was funded at $305,835. The final report for this year's effort will become available in July 1965.

EXPERIMENTAL APPARATUS

To perform the experimental program, a test vehicle was designed and fabricated. The test vehicle allows wide variation and control of converter operational parameters. In addition to the parametric control, the test vehicle is provided with an active collector guard ring assembly which eliminates side-wall emission problems. The tungsten-molybdenum test vehicle has an additional reservoir which can permit the introduction of surface additives to evaluate their effect on converter performance.

The instrumentation used to provide control and performance observation is shown in the block diagram, Fig. 1. The left-hand blocks represent temperature control components while the remaining blocks represent the test vehicle and instrumentation. The follower circuits maintain the guard ring and collector at the same potential. The instrumentation permits three different modes of converter operation.

1. Static high current.

2. Dynamic high current.

3. Low current work function.

Each of the three modes of operation are used for the performance evaluation of the various electrode materials.

PERFORMANCE EVALUATION

Utilizing the low current mode of operation, retarding plots are made to determine the cesiated collector work function variation with surface temperature. The collector work function data is presented in Fig. 2. The emitter work function is determined from measurement of saturation current, and is illustrated in Fig. 3.

Parametric data was obtained using each of the following parameters as the independent variable:

1. Emitter temperature.

2. Interelectrode spacing.

3. Cesium reservoir temperature.

4. Collector temperature.

The information obtained from this parametric study has two-fold importance; it provides reliable design data, and insight to the conversion process. A typical parametric curve, with cesium reservoir temperature as the independent variable, is presented in Fig. 4.

ANALYTIC MODEL

Rapid progress has been made in synthesizing an analytic model which accurately describes the conversion process. The availability of data from the performance evaluation has permitted a mathematical formulation. The available data provides the necessary information to determine constants which arise during the formulation. The data also provides an accurate rule to the applicability of the model. The model developed to date accurately describes the conversion process over a reasonable variation of parameter values.

FUTURE WORK

Thermionics supporting research will be continued during FY 1966 and will emphasize converter performance improvement and refinement of the converter

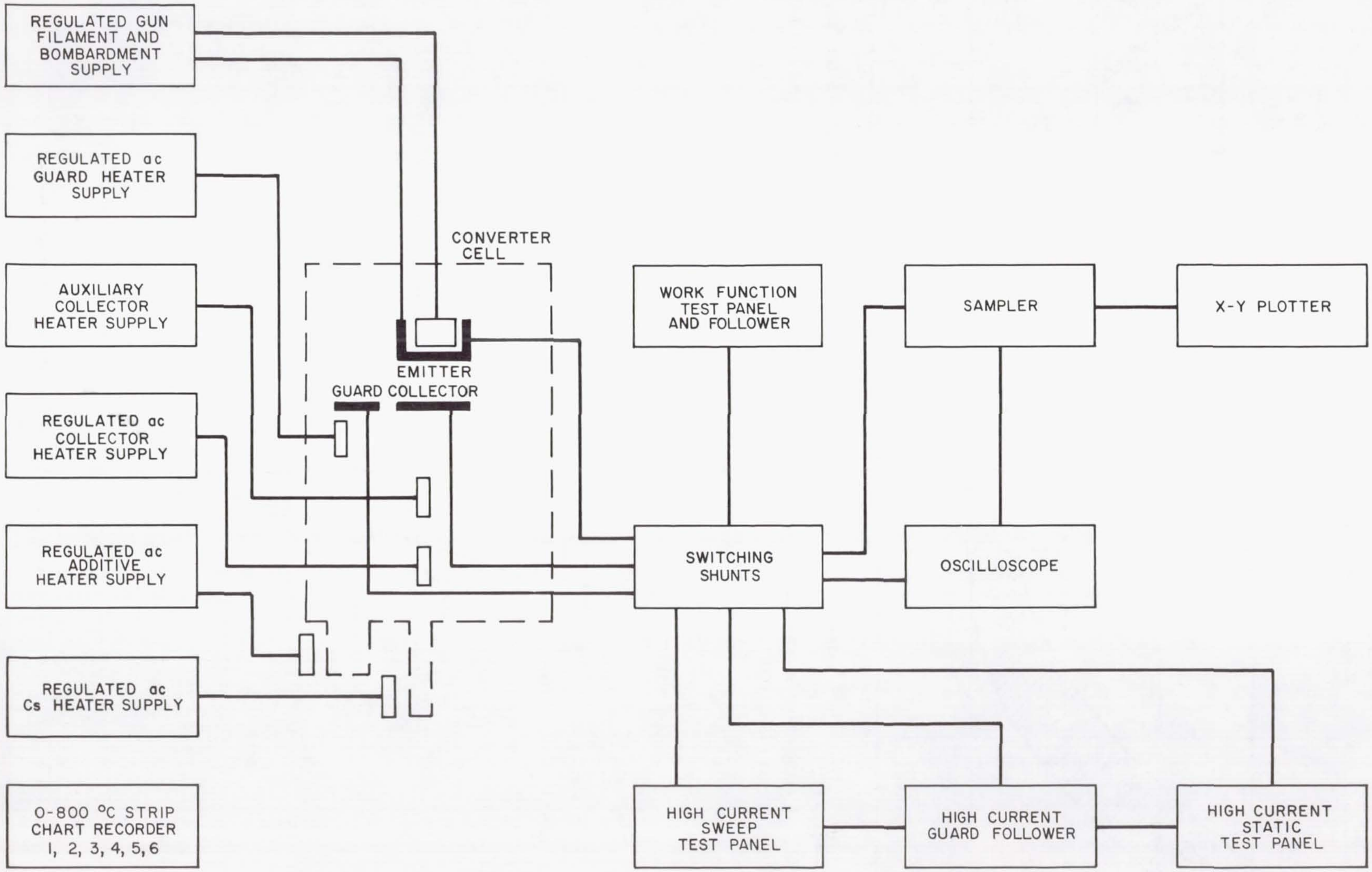


Fig. 1. Block diagram of test equipment

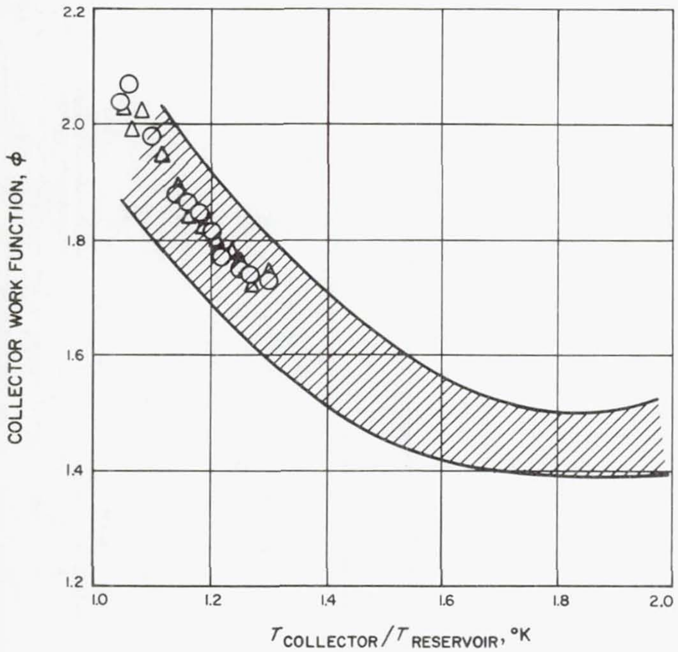


Fig. 2. Collector work function correlation

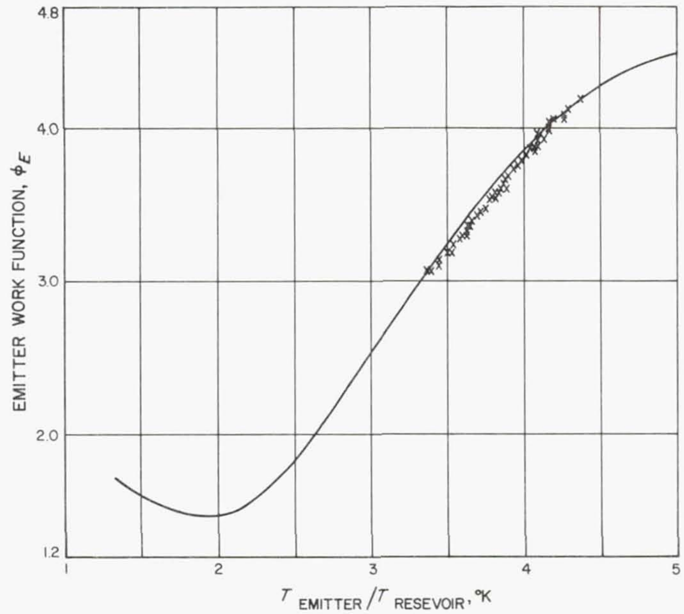


Fig. 3. ϕ vs T_E/T_R correlation

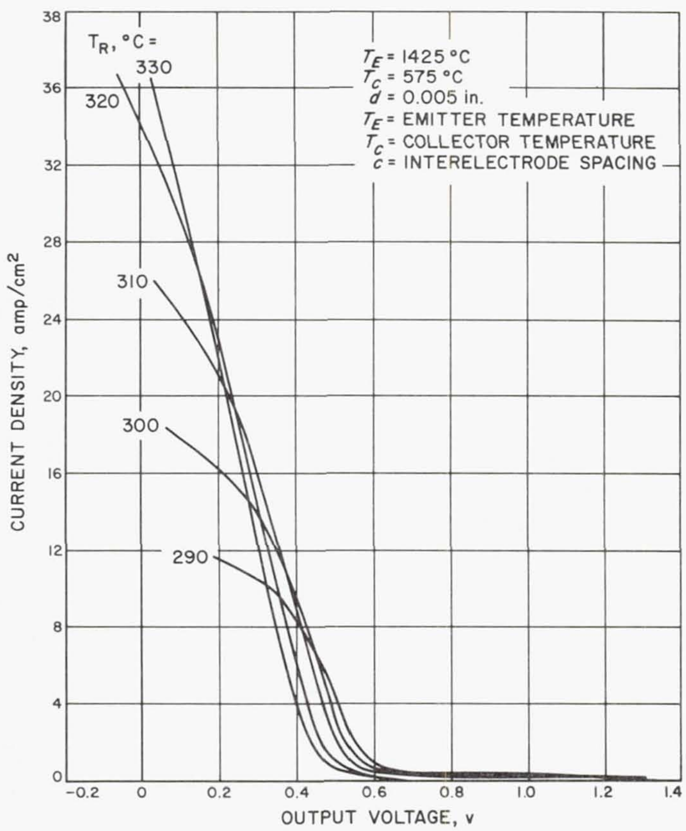


Fig. 4. Parametric curve - C_s reservoir temperature variable

analytical model to include a wider range of parameter values. The work will be performed by TEECO under Contract 951262 and is funded for $200, 600.

Two different approaches will be taken to obtain improved converter performance. The first approach is a continuation of effort in the evaluation of the effectiveness of cesium-floride as a surface additive. Experimental evidence indicates the introduction of a surface additive reduces the cesium pressure required to achieve a given emission. The lower cesium pressure reduces the number of collisions in the interelectrode region and hence reduces collision losses. The surface additive will be used in a tungsten-molybdenum test vehicle.

The second approach utilizes an additive to reduce plasma depletion losses. The plasma additive is an inert gas which presents a high collision cross-section to migrating cesium ions while projecting a minimum collision cross-section to the low speed (1 ev) electrons. The inert gas inhibits ion migration toward the electrodes and therefore, reduces the ion-electron rate at the electrode surfaces. The plasma additive will be evaluated in rhenium-molybdenum and tungsten-molybdenum test vehicles.

Page Intentionally Left Blank

SOLAR THERMIONIC TEST FACILITIES
NASA Work Unit 123-33-02-03
JPL 323-30701-2-3420

The solar test facility includes all of the required monitoring equipment for the calibration and checkout of photovoltaic devices varying from individual solar cells and modules to complete solar power panels. Solar thermionic test equipment includes a modified searchlight tracker capable of supporting and tracking mirrors to 10.1 ft in diameter with an accuracy of 0.5 min of arc in gusts to 10 knots. Ancillary equipment includes a 11-in.-ID vacuum chamber with a 1.00-in. thick by 14.00-in. diameter fused silicon window, a hand operated open-cylinder type solar flux control and resistance load (Fig. 1a and 1b).

Fig. 1a. Solar thermionic generator test equipment

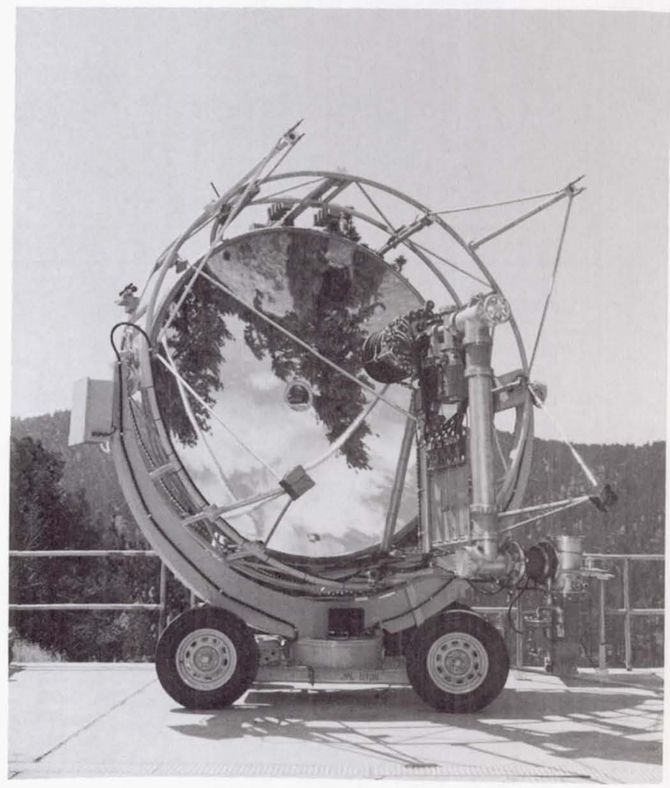


Fig. 1b. Solar thermionic generator test equipment

The system utilizes a 200 channel automatic data acquisition system, allowing permanent data recording and visual display of all data.

ACTIVITIES

During the third quarter of 1964, JPL delivered a five-converter solar thermionic generator to the Table Mountain Test Facility for sunlight evaluation.

During the first quarter of 1965, effort was directed to completing the final test reports for programs of the previous year. Reports on the original 9.5-ft-diameter mirror, designated S/N1, a lightweight 9.5-ft mirror (S/N2), and the test of thermionic generator (JG-2b) have been issued and are presently in publication.

The second quarter has been involved with contract negotiations with the new contractor (Lockheed) and his indoctrination with JPL site capabilities and requirements. Preparations for moving to a new area at the Table Mountain Site are complete and by July 1, 1965, moving and reassembly of equipment will have been completed.

The test activities at the site planned for the immediate future include sunlight testing of a three-converter generator, a four-converter generator (JG-4), and installation and checkout of an improved solar tracking system. Figure 2 is a schedule of the Table Mountain Test Facility activities for 1965.

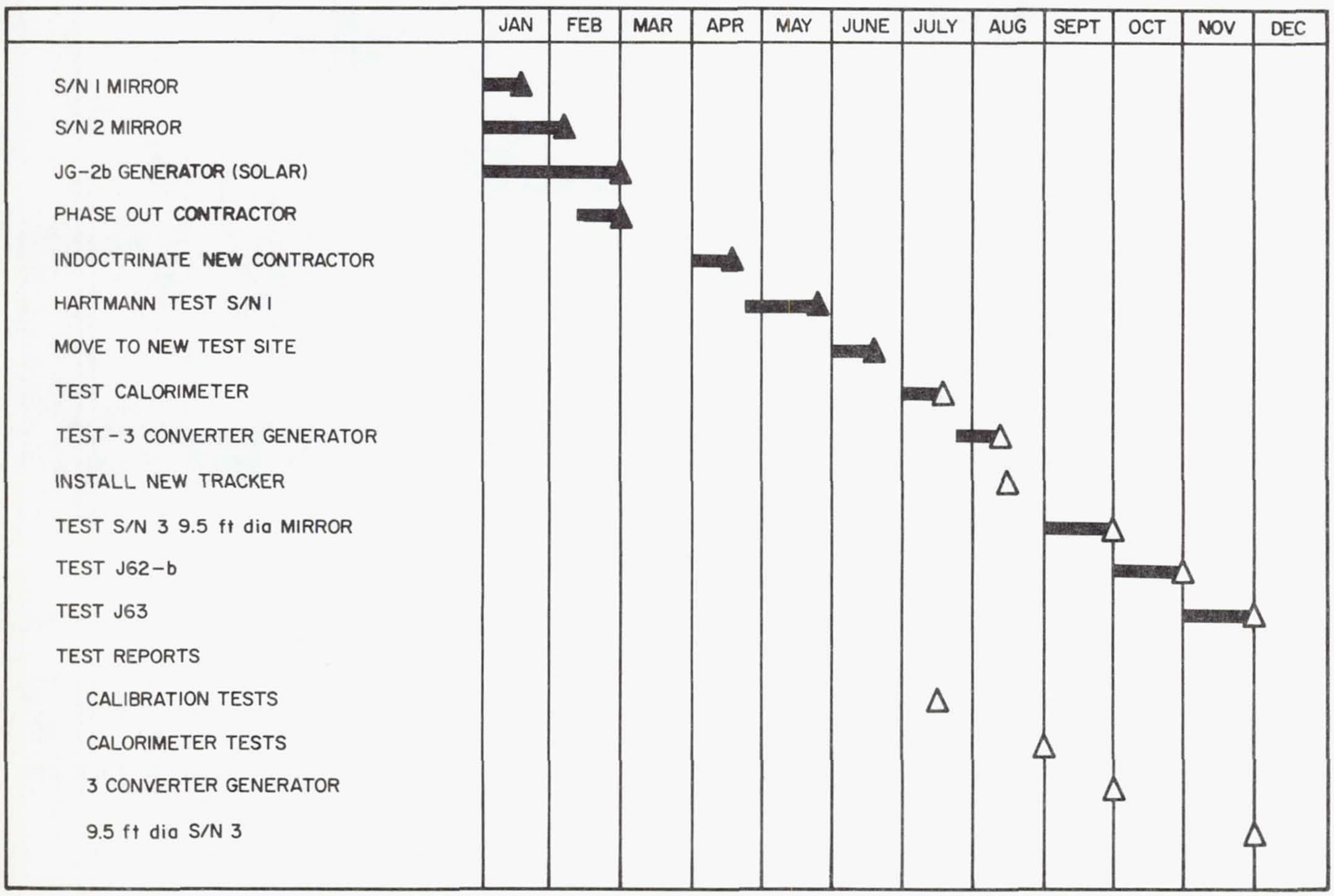


Fig. 2. Table Mountain activities for 1965

SOLAR CONCENTRATORS
NASA Work Unit 123-33-06-01
JPL 323-30401-2-3420

In 1963 under Contract 950239 JPL initiated development and fabrication of a large-diameter (9.5-ft) nickel electroformed male master of a solar concentrating mirror. To accomplish this a spincasting technique was employed to form the mold for the fabrication of this master. The geometric accuracy of the spincast mold attained was approximately ±1 min of arc and resulted in the production of ±4 min of arc male masters and replicas with 2 sigma slope errors of less than ±10 min of arc.

Extensive testing has been accomplished at JPL on the first 9.5-ft-diameter mirror produced by this technique. This mirror (S/N 1) has delivered up to 3300 thermal w into a 1.00-in. diameter calorimeter cavity located at the best focus of the mirror. An overall efficiency of 52% was achieved. This mirror, a proof of the feasibility of this technique of mirror forming, weighed approximately 500 lb. It was demonstrated recently on a second replica (S/N 2) of the same master that a 9.5-ft-diameter mirror weighing 92.6 lb could be produced.

The environmental testing of electroformed mirrors had not been actively pursued at JPL until the last quarter of 1964. In an attempt to gain insight to the problems of system components and ancillary equipment, efforts have been initiated in the areas of:

1. Environmental testing of 5-ft-diameter mirrors and support structures.
2. 9.5-ft-diameter mirror master refurbishing and replication.
3. Generator support structures.
4. Solar flux controls.
5. Cesium reservoir controls.
6. Improved 5-ft-diameter mirrors.
7. 11.5-ft-diameter mirror design and fabrication.
8. Laboratory mirror test stand.

In order to further support development of a complete solar thermionic system a program to study the requirements of a Solar Thermionic Experimental Flight was initiated to show areas which require further development or refinement, interface problems, missions of interest, etc. Contract 950852 for $77,893 was awarded to General Electric for this purpose. Three different missions were suggested for the flight experiment. Included in the requirements were selection of the orbits, launch vehicles, selection of secondary experiments, and thermionic systems size. Conceptual spacecraft designs were included for each of the missions studied. Drawings were prepared for these conceptual spacecraft as well as for the thermionics experiment.

The results of the study indicate that a successful thermionic flight experiment is feasible within the current component state of the art. In addition, the study results show that a solar oriented spacecraft of the type required for conducting a solar thermionic flight experiment offers a unique space platform from which many valuable scientific and engineering experiments may be performed.

Table 1 lists the various orbits studied, their advantages and disadvantages. Table 2 is a summary of the selected mission parameters. Table 3 presents the performance parameters for the solar thermionic experiment, and Table 4 is a brief summary of the secondary experiments recommended for this flight. The conceptual spacecraft is shown in Fig. 1.

This effort was completed in April 1965. The final report on this effort is available for distribution.

Contract 951162 for \$ 23,600 was awarded to Electro-Optical Systems for further evaluation of secondary experiments. This effort is in direct support of the preceding Thermionics Flight Study program in that it is organized to expand the minimal list of 50 interesting and possible secondary experiments which could be utilized in the event of a solar thermionic experimental flight.

The program will result in the experiments listed in the order of priority in which they should be flown and conceptually laid out within the spacecraft concept from the G. E. effort. Where instrumentation is not available, suggestions as to the type of instrument needed will be made.

The schedule for this program in shown in Fig. 2.

9. 5-FT - DIAMETER MASTER REFURBISH AND REPLICATION

During 1962-63, General Electric Co. (MSVD), under contract to JPL, fabricated the first 9. 5-ft - diameter mirror and master. The result of this fabrication produced a mirror with several defects including dual focus and anode damaged areas as well as strains due to weather (and possibly inadequate cleaning). It was not clear as to when the dual focus conditions occurred; the most economical way to determine if the problems were due to the master was to fabricate a second replica (S/N 2) and to test this replica. This step was taken and tests have proven that the master does not have the dual focus condition.

Since the master was good, except for stains and the anode areas, it seemed appropriate to attempt to remove the stains by buffing and to repair the anode areas as much as possible. Fabrication of a third replica (S/N 3) for use in the test of solar thermionic devices would determine the feasibility of refurbishing mirror masters. It is hoped that this technique could result in the production of replica mirrors of a better quality than that attained by the S/N 1 and 2 mirrors. To accomplish this, the 9. 5-ft - diameter mirror master required, besides polishing and replications, a vacuum-deposited aluminum and Si0 coating to preserve the finish and reflectivity.

Purchase orders were placed with EOS to refurbish the master and provide replicas. To date the mirror master has been buffed and polished. The large anode damaged area was considerably reduced in size by this process (5.00 to 1.00 in. diameter). The master is presently undergoing plating to form the replica and the aluminum torus mounting. The delivery of an uncoated mirror is scheduled by

Table 1. Advantages and disadvantages of various orbits

Orbit	Advantages	Disadvantages
Low altitude circular (325 nm)	1. Can be obtained with a low cost, highly reliable launch vehicle.	1. Has a short period and low light-to-shadow ratio. This results in frequent thermal cycling and does not provide a long uninterrupted light period for evaluation of the solar thermionic experiment. 2. Of least interest for making scientific measurements because a relatively large number of experiments have already been conducted in this range. 3. Because the boost capability required is relatively small, this orbit makes very inefficient use of any of the launch vehicles available. 4. Requires numerous ground stations for handling the TT&C functions.
Modified sun-synchronous daylight (1000 nm circular)	1. Provides shadow-free period for the early phase of the mission with shadow periods being introduced in the latter phase. 2. TT&C functions require a maximum of two ground stations. One station may be sufficient. 3. Can be obtained with a low cost highly reliable launch vehicle. 4. Altitude is of interest for making scientific measurements and ideal for conducting many of the secondary engineering experiments considered.	1. Falls in a severe region of the Van Allen radiation belt and may be hazardous to photovoltaic power supply as well as electronic components of spacecraft.

Table 1. (Cont'd)

Orbit	Advantages	Disadvantages
Highly elliptical orbit (200 nm x 25,000 nm)	1. High light-to-shadow ratio. 2. Scientific measurements of interest. 3. Can be obtained with a medium cost highly reliable launch vehicle. 4. Long orbit period reduces thermal cycling.	1. Requires numerous ground stations for handling TT&C functions. 2. Has lengthy shadow periods (2 hr). 3. Shadow history is erratic.
Stationary earth synchronous (19,300 nm)	1. Can handle TT&C functions from one ground station. 2. Provides shadow-free periods for the early phase of the mission with shadow periods being introduced in the latter phase.	1. Establishing and maintaining orbit requires a complex station keeping system. 2. Expensive launch vehicle (ATLAS-AGENA D) of relatively low reliability required. 3. Not very interesting for scientific measurements. 4. Has lengthy shadow periods (1.17 hr).
Solar probe	1. Spacecraft always in the sun. 2. Secondary scientific experiments of great interest.	1. Large variation in solar intensity. 2. Effects of shadow cannot be evaluated. 3. Desirable orbit requires an unproven launch vehicle (ATLAS/AGENA D/X259). 4. Launch vehicle relatively expensive and of low reliability. 5. High priority ground stations required (DSIF). 6. Requires directional antenna onboard the spacecraft.

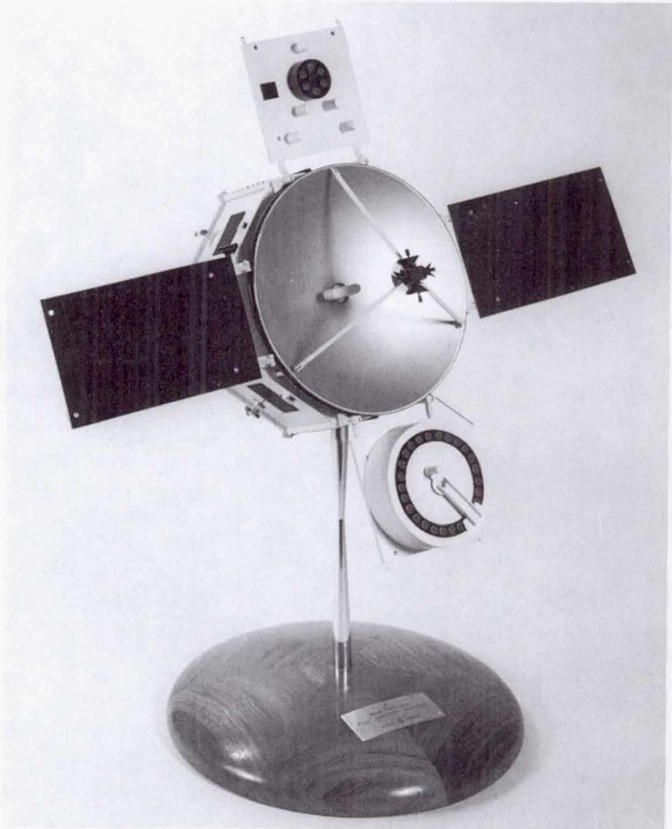


Fig. 1. Conceptual spacecraft solar thermionic flight experiment

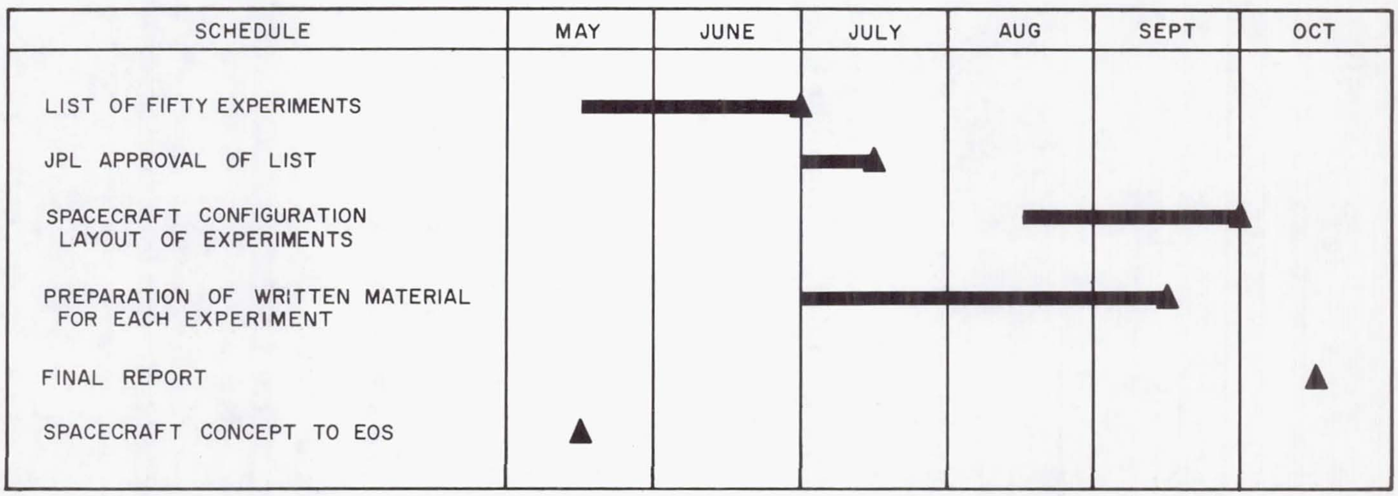


Fig. 2. Secondary experiment evaluation schedule

Table 2. Summary of mission parameters

Parameter	Mission A	Mission B	Mission C
Type of orbit	Modified Sun-synchronous	Highly elliptical	Low altitude circular
Orbit altitude, nm	1000	25,000 apogee 200 perigee	325
Orbit inclination, deg	101.84	45	30
Orbit period, hr	2.07	14.0	1.61
Orbit maximum dark period, hr	0.4	2.09	0.617
Launch vehicle	Improved Delta DSV-3E	Improved Delta DSV-3E[a]	Improved Delta DSV-3E
Launch site	WTR	ETR	ETR
Thermionic system concentrator diameter, in.	50	50	50
Thermionic generator power output, w	144	144	144
Thermionic system efficiency, %	8.2	8.2	8.2
Secondary experiments	See Table 4	See Table 4	See Table 4
Spacecraft weight, lb	360	373	404

[a]First stage floxed 30%

Table 3. Thermionic system performance parameters

Performance parameters	
Converter emitter temperature	2000°K
Converter electrode spacing	2 mils
Converter emitter material	Rhenium
Converter sleeve thickness	0.0025 in.
Converter emitter area	2 cm^2
Converter operating point	Peak efficiency
Converter power density	18-w/cm^2
Converter voltage output	0.85 v
Converter efficiency	17.4 %
Concentrator diameter	50 in.
Concentrator rim angle	60 deg
Concentrator geometric error, 3	12 min
Concentrator reflectivity	90 %
Concentrator blockage factor	5 %
Concentrator-absorber efficiency	67 %
Thermionic generator aperture diameter	0.71 in.
Thermionic generator efficiency	12.2%
Thermionic generator power output	144 w
Thermionic generator voltage (Four converters in series)	3.4 v
Thermionic system efficiency	8.2 %

Table 4. Recommended secondary experiments

Priority	No.	Experiment	Major reasons for selection	Orbit Compatibility[a] I	II	III
Priority "A"	1	Space evaluation of solar reflective surfaces	Results of major importance to the development of solar thermionics and other solar power systems employing concentrators. Also helpful in evaluating the primary experiment.	X	X	X
Priority "A"	2	Micrometeoroid measurement	Important scientifically and to evaluation of the primary experiment. Also needed for complete evaluation of Experiment 1.	X	X	X
Priority "A"	3	Proton and electron spectra and direction	Important scientifically and to evaluation of the primary experiment. Also needed for complete evaluation of Experiments 1 and 8.	X	X	
Priority "A"	4	Measurements of ultra-violet radiation flux	Important scientifically and to evaluation of the primary experiment. Also needed for complete evaluation of Experiments 1, 5, and 8, and supplements Experiments 10 and 11.	X	X	X
Priority "B"	5	Space evaluation of thermal coating	Relatively simple experiment which yields needed information on thermal coatings to be used on space vehicles. Experiment package already developed. Experiment makes use of Sun-pointing features of the spacecraft.	X	X	X
Priority "B"	6	Laser experiment	Important to the development of lasers as a means of space communication.	X	X	X
Priority "B"	7	Low thrust electric engine	Important to the development of low thrust electric engines for use in attitude control systems and space propulsion in general.	X	X	X

Table 4. (Cont'd)

Experiment			Major reasons for selection	Orbit Compatibility[a]		
				I	II	III
Priority "B"	8	Radiation effects on solar cells	Important to a more complete understanding of solar array degradation from radiation. Results needed to improve solar cell power supply design. Also makes use of the sun pointing feature of the spacecraft	X	X	X
	9	Space evaluation of a new infrared detector	Important to the development of better IR detectors for use in attitude control systems.	X	X	X
	10	Solar x-rays	Important scientifically and makes use of the Sun-pointing feature of the spacecraft. Also supplements Experiments 4 and 11.	X	X	X
	11	Solar γ-rays	Important scientifically and makes use of the sun-pointing feature of the spacecraft. Also suplements Experiments 4 and 10.	X	X	X
	12	Lyman-alpha experiment	Important scientifically and makes use of the Sun-pointing feature of the spacecraft.	X	X	X
	13	Earth albedo	Important to a better measure of the Earth's albedo. This information is of value scientifically and to the thermal design of space vehicles.			X

[a]Orbit I - Modified sun-synchronous (1000 nm - 101.84-deg inclination)

Orbit II - Highly elliptical (200 nm x 25,000 nm - 45-deg inclination)

Orbit III - Low altitude circular (325 nm 30-deg inclination)

July 1, 1965 with vacuum coating to occur either at JPL during the month of September or at a commercial mirror coating facility within 8 mo from the July date.

This mirror when completed will be sent to the JPL Solar Test Facility for test and evaluation.

Figure 3 shows the scheduled milestones for this effort.

GENERATOR SUPPORT STRUCTURES

Thermionic systems testing at JPL has been conducted employing a prototype of a 5-ft-diameter mirror and generator support structure. This structure, procured under PO V5-332091, is used to support and position a solar thermionic generator at the focus of the concentrating mirror. The systems testing has been conducted during the past six months and has required the continual utilization of the single set of support structures available to JPL. Examination of this structure indicates that overtesting has made further utilization questionable and possibly dangerous to the other components tested concurrently.

Since the JPL designed structure successfully passed all of the Mariner C, solar power panel, (Atlas-Agena) type approval level environmental tests and further testing is desired, this effort will procure two sets of this fixed structure with some mirror refinements, mainly in the area of attachment of the thermionic generator.

Also, it is desirable to investigate foldable support structure concepts and to test them environmentally in order to determine feasibility of incorporating them into a solar thermionic system. Should this concept prove feasible the launch packing factor for the system will be greatly improved.

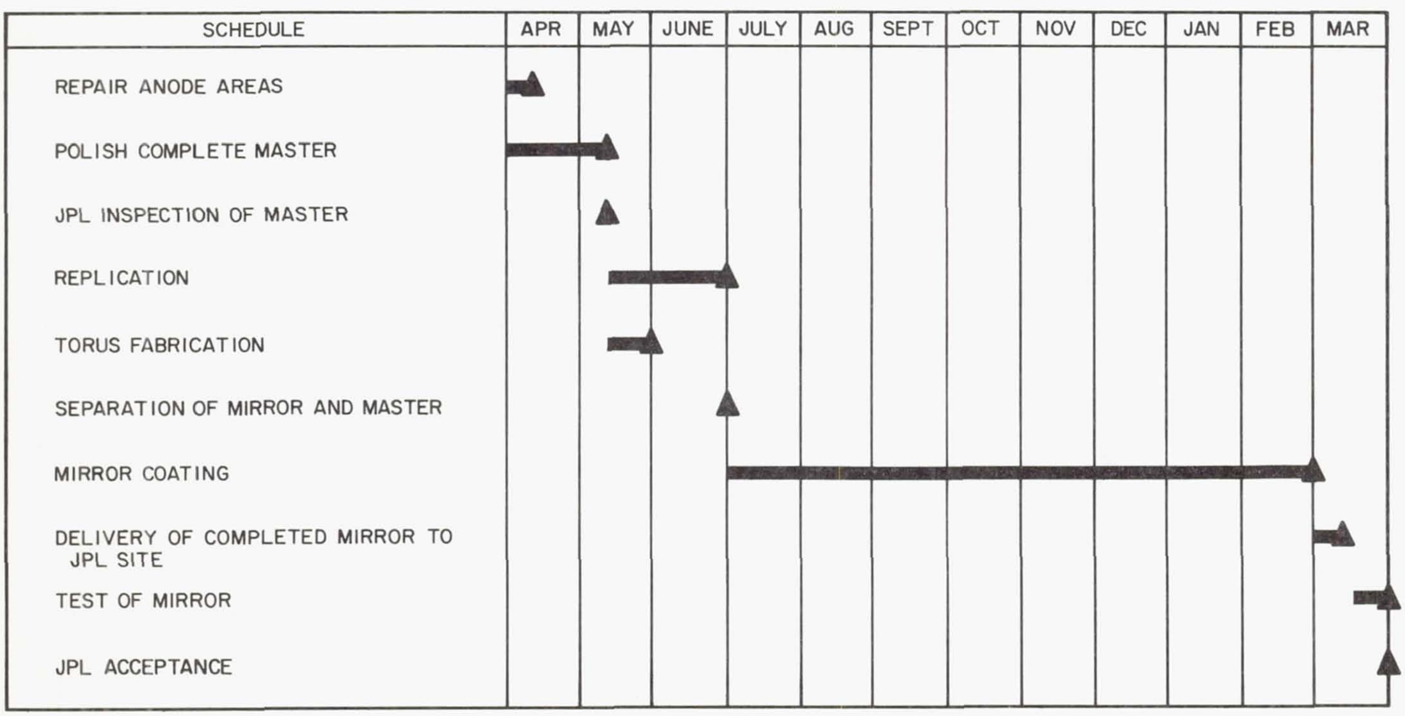


Fig. 3. Mirror master repair schedule

It is anticipated that this effort will result in a refined, fixed, coaxial support structure within three months ARO and delivery of the folding structure within six months ARO.

IN-HOUSE SYSTEMS TESTING

Recently, active pursuit of programs in support of solar thermionic systems development has been initiated, especially in the area of engineering model environmental testing. The model tested consisted of a lightweight, nickel-electroformed, 5-ft-diameter solar concentrator, tubular aluminum coaxial conductor/generator support structure, and mockup generator as shown in Fig. 4. Environmental evaluation of this model has revealed design deficiencies and component fabrication weaknesses which will be corrected on future models.

The environmental test program, model design and test results have been reported in JPL Space Programs Summary No. 37-30 and 37-33, Vol. IV. JPL environmental test Specifications GMP-34218-TST was used as a guide for this evaluation program. Type approval test levels resulted in no apparent damage to either mirror, conductor/support structure, or mockup generator. Saturn-Centaur acoustic noise level tests revealed a design and fabrication weakness in the area of mirror skin to torus attachment which is being corrected for future models.

This is the first successful attempt to completely environmentally test a solar thermionic system. The evaluation of the conductor/support structure showed that the magnetic field effects of high currents (50-amp) flowing through it can be minimized and possibly eliminated. Mechanical vibrations (axial) were performed for the first time at JPL using the unique technique of paralleling three vibration exciters operated in phase (Fig. 5). Figures 6a and 6b show the instrumentation location on this model. Figure 7 shows the model after the completion of all tests.

Programs are now underway to procure additional solar concentrators, with improved torus attachment, and fixed and moveable generator support structures to allow further and more thorough evaluation of system components within the next report period.

12-FT-DIAMETER MIRROR MASTER AND REPLICA

The experience of JPL has been that when testing a solar thermionic generator on Earth, the solar irradiance is not sufficient to allow use of the same size concentrator that would be used in space. For this reason, to test on Earth a generator which would utilize a 5-ft-diameter mirror in space, a considerably larger diameter mirror is required to supply the required thermal power. From past experience and anticipating, within the next few years, having a thermionic generator of the multi-converter variety (possibly 16 converters) which could be used with a 9.5-ft-diameter mirror in Earth-space, it has been determined that a mirror 11.5 ft in diameter will be required for Earth testing. This mirror should be capable of supplying all of the thermal power requirements of thermionic generators to be produced for JPL within the next 5 yr. This will also be the first time that a program to fabricate a single skin mirror of this size has been attempted. The program will include the fabrication of a spincast mold, an electroformed male master and an electroformed nickel replica as well as the vacuum depositing of aluminum and SiO to coat this mirror. It is anticipated further that each of these tasks will be accomplished at one vendor facility under a firm fixed-price contract.

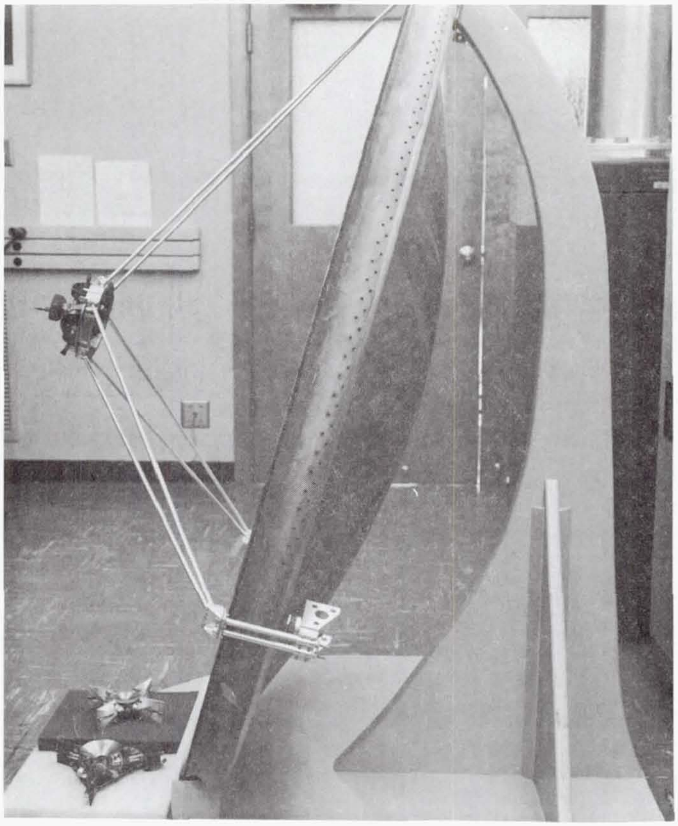


Fig. 4. Engineering evaluation model solar thermionic system

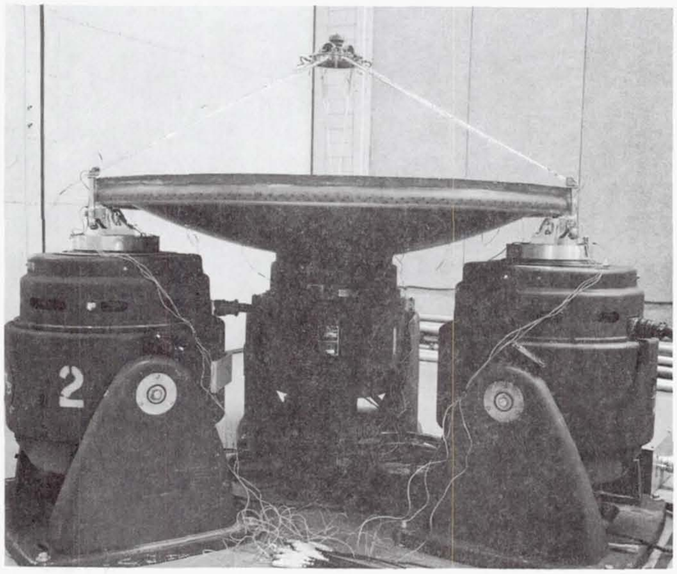


Fig. 5. Axial acceleration of model system using 3 exciters in phase operated

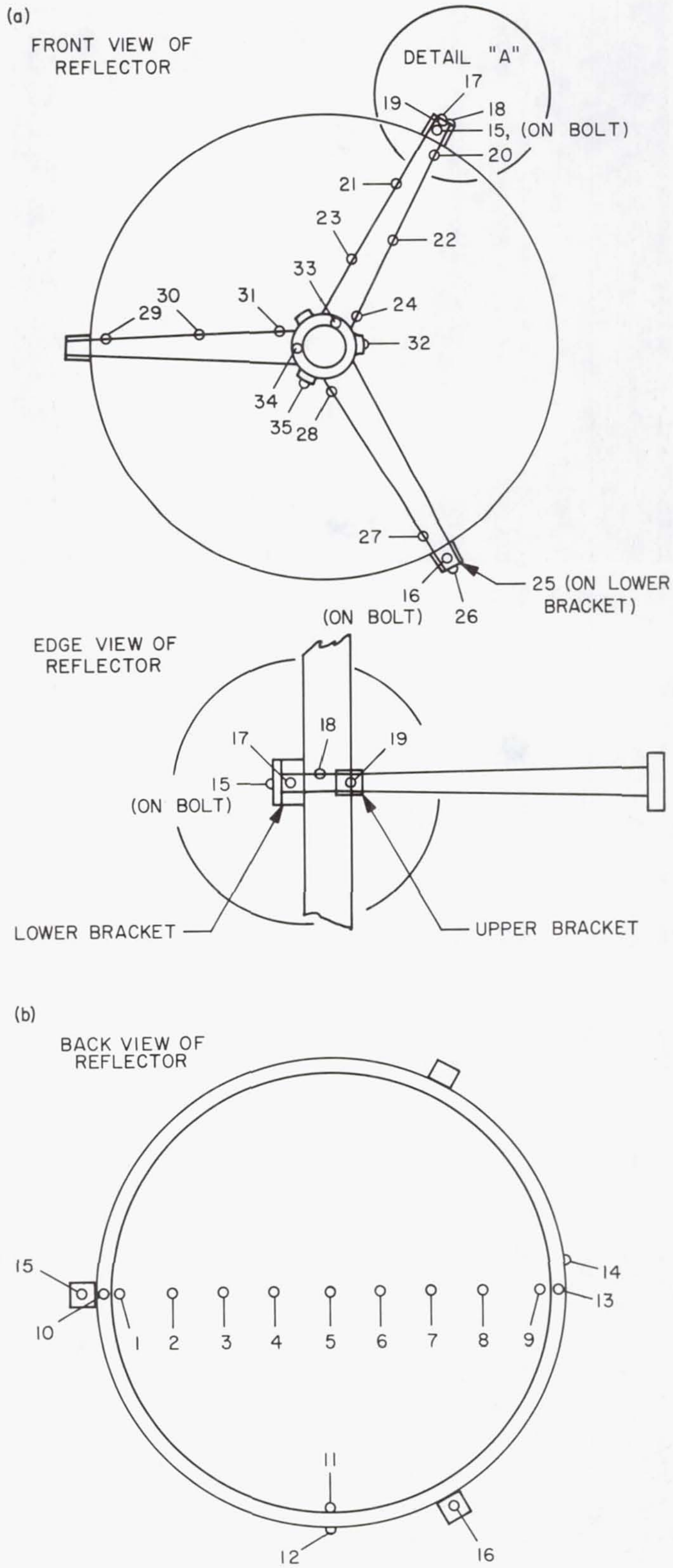


Fig. 6. Location of Instrumentation

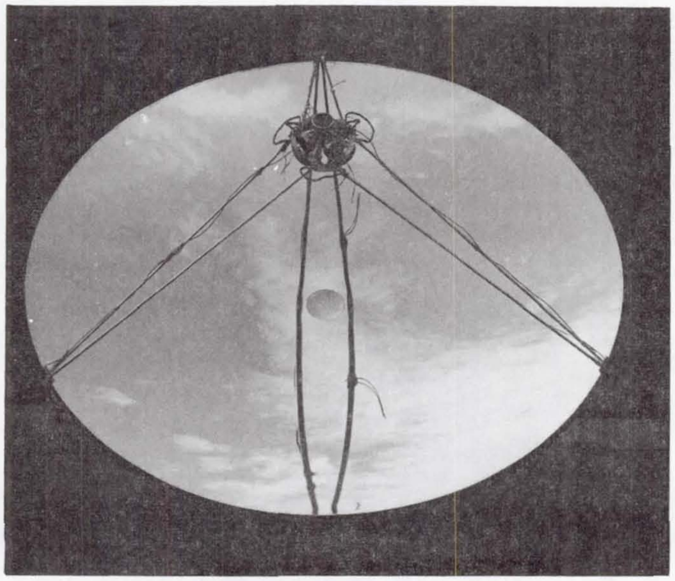


Fig. 7. Engineering model after complete and extensive environmental testing

Replica specifications include:

1. Rim angle 52.5 deg.
2. Geometric accuracy less than 5 min of arc (2 sigma).
3. Total weight nominal 350 lb.
4. Reflectance 85% in visible region.

It is anticipated that this effort will be completed within 9 mo ARO. If the anticipated success is realized a milestone in large-diameter-mirror fabrication techniques and costs will have been reached and could point the way to further progress in this area.

CESIUM RESERVOIR TEMPERATURE CONTROLS

The objective of this program is to design, fabricate, and test-flight engineering evaluation models of both active and passive cesium reservoir controls of solar thermionic power converters.

As long as cesium reservoirs are a part of the thermionic converter it will be required that the temperature/pressure of the cesium in the converter be maintained within specific values to allow optimum converter operation. At present active control is used and the control design is not made with flight hardware as a goal. This program should result in a universal control design for both active and passive concepts which will be adaptable for a variety of converter geometries and requirements as well as be a step toward flight-type hardware.

After acceptance testing these devices will be thoroughly evaluated at JPL during tests with actual converters to show areas for further refinement as required.

The passive control concept will most probably be of the bimetallic rotating cylinder type; both control concepts will monitor temperatures for the controlled parameter. Future models may have the capability of servo control by monitoring the electrical performance of the thermionic converter and incorporate a feedback circuit to maintain optimum performance.

Delivery of these first models is scheduled for December 1965.

SOLAR FLUX CONTROLS

A request for proposal was submitted to industry to design and fabricate a solar flux control to limit the radiant power input into a thermionic power generator and is considered a logical step in the development of a flight-type solar thermionic power system. A solar thermionic generator which is designed to provide power for a 0.2- to 1.0-AU mission must operate in a solar flux which varies by a factor of 25 over the duration of the mission (1.0 AU, 130 w/ft^2 to 0.2 AU, 3250 w/ft^2). This means that with a 5-ft-diameter mirror the concentrated thermal power which must be accommodated is nearly 63,000-w within a 0.6-in. aperture diameter.

The proposed program will result in the analysis, design, fabrication, and solar-testing of a flight version of a solar flux control that could possibly be employed for solar thermionic powered spacecraft for missions ranging from 1.7 to 0.2 AU.

LIGHT-WEIGHT 5-FT-DIAMETER MIRRORS

Thermionic system testing conducted at JPL during the past 6 mo has utilized two 5-ft-diameter mirrors. One of these mirrors was severely damaged during Saturn-Centaur acoustic noise level testing in that the torus-to-skin attachment was found to be inadequate. Figure 8 shows this mirror mounted for thermal vacuum testing.

The second mirror has been severely overtested and it is felt that continued testing of this mirror would not yield meaningful data. The test program to date has pointed out several weak points in mirror/torus attachment designs which must be rectified before a mirror can be considered as flight worthy.

A program has been initiated to procure two concentrators to replace those noted above. One of these mirrors will weigh 15 lb, the other 10 lb. This lighterweight mirror will have a skin on the order of 0.007-in. thick and an aluminum chem-milled torus and will be used to evaluate the feasibility of fabricating higher specific power solar thermionic systems.

The mirrors will be used in conjunction with the fixed and moveable support structures being developed concurrently and both will be environmentally tested in the JPL thermionic systems development program.

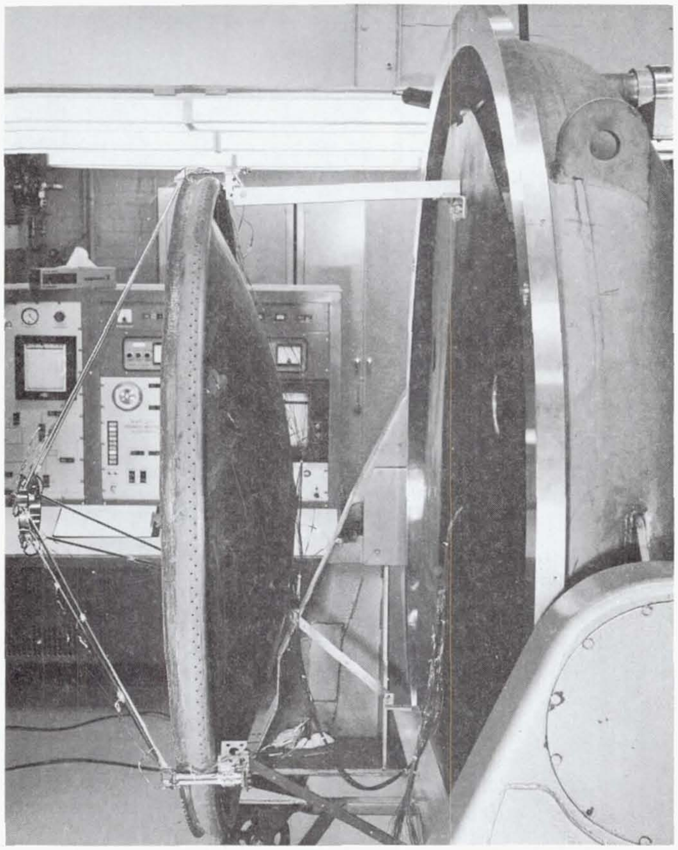


Fig. 8. Mirror mounted for thermal vacuum testing

THERMAL ENERGY STORAGE
NASA Work Unit 123-33-07-01
JPL 323-30501-2-3420

Solar thermionic electrical power supplies are potentially capable of providing spacecraft power for many types of missions and could offer less weight, array areas, and cost than other power generating systems. With the incorporation of thermal energy storage (TES), this power supply would have the additional capability of supplying continuous power during sunless portions of a mission.

In 1960, NASA initiated sponsorship of an effort to develop high temperature thermal energy storage materials; during this effort two of the most interesting materials investigated were $2MgO$-$3BeO$ (M. P. 1827°C, H_f = 265 whr/lb) and MgO-Al_2O_3-$4BeO$ (M. P. 1747°C, H_f = 200 whr/lb). Efforts prior to December 31, 1964 have been mainly on containment and compatibility. The results indicate that there is no significant compatibility problem between these materials and rhenium for at least 1000 hr, cycling 50°C about the melting temperature.

PRESENT PROGRAMS

Encouraged by the compatibility data, two new efforts were initiated to further the development of thermal energy storage. The two programs are the TES feasibility model and TES supporting research. The former effort is being implemented by contract 950976 with Thermo Electron Engineering Corporation (TEEC) for $56,883. The effective dates for this are March 2, 1965 to August 2, 1965; the principle investigator is S. Morra. The object of this program is to incorporate a right circular cylindrical rhenium container of bulk $2MgO$-$3BeO$ (oxide) with a thermionic converter and to demonstrate the feasibility of TES during actual converter testing.

A limited computer computation was performed to facilitate the selection of the model design parameters and mode of operation which would yield the most meaningful device. Figure 1 shows a cutaway view of the device design including thermal shielding and electron bombardment heater. In order to maximize life and reliability of the model the TES container will be filled to 70% by volume with premelted eutectic composition as this percentage has been successfully contained during previous investigations.

The thermionic converter selected was the S VIII type but will be modified to include a solid rhenium emitter and an 0.008-in.-thick rhenium spacer as shown in Fig. 1.

Individual oxides (MgO and BeO) have been successfully purified, mixed, and melted to form the eutectic composition. The electron beam welds of the rhenium crucibles used in the melting operation have been both x-ray and microscopically examined and have been found satisfactory.

The schedule (Fig. 2) shows major milestone completion dates. To date, no major problems have been noted which should alter the schedule or program objectives.

Upon successful completion of this program it is anticipated that additional models will be procured to demonstrate reproducibility of the techniques developed.

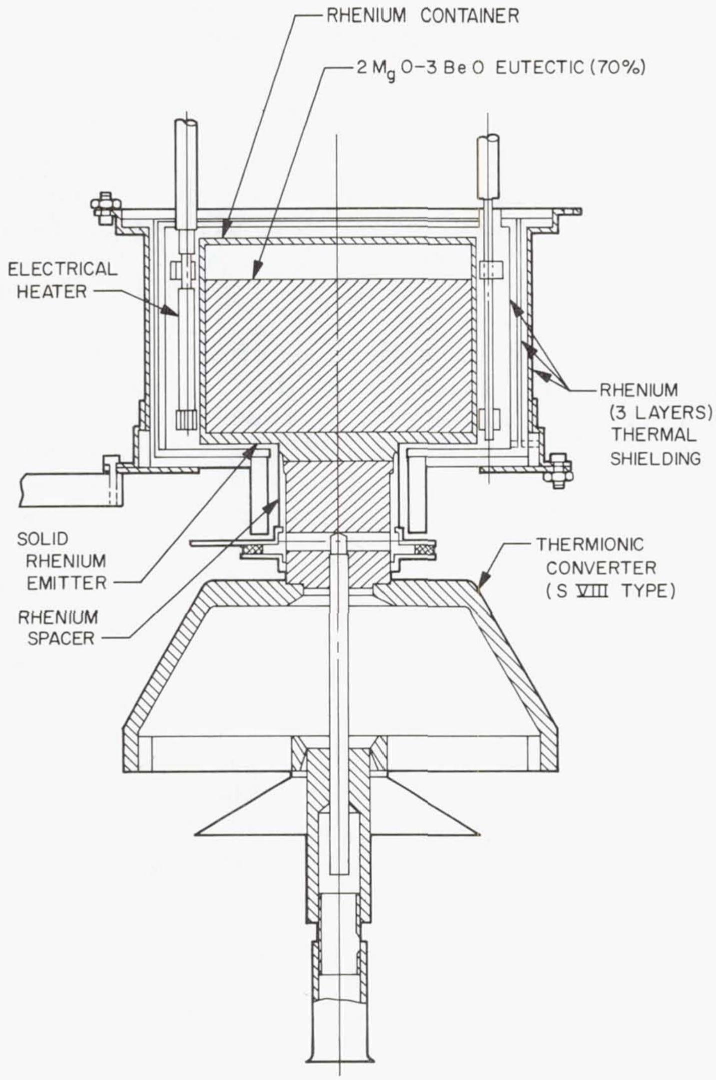


Fig. 1. Cutaway view of feasibility model design

After testing to verify performance, these models will be subjected to life-testing at JPL.

The TES supporting research program is being carried out by means of contract 950978 with Battelle Memorial Institute for $228,000. The contract period is April 1, 1965 to April 1, 1966; the principal investigator is P. Moak. This program was initiated to obtain important thermophysical properties of Thermal Energy Storage Material. Two oxides of most immediate interest will be evaluated in this program, Be_2O_3MgO and Be_3O_4-Mg_2O_3-Al_2O_3. Information obtained from this program will allow realistic engineering design of operational TES/thermionic models in the future.

The effort to date has been mainly an analysis of existing data on the two melt materials noted above and developing the analytical techniques required to evaluate these materials.

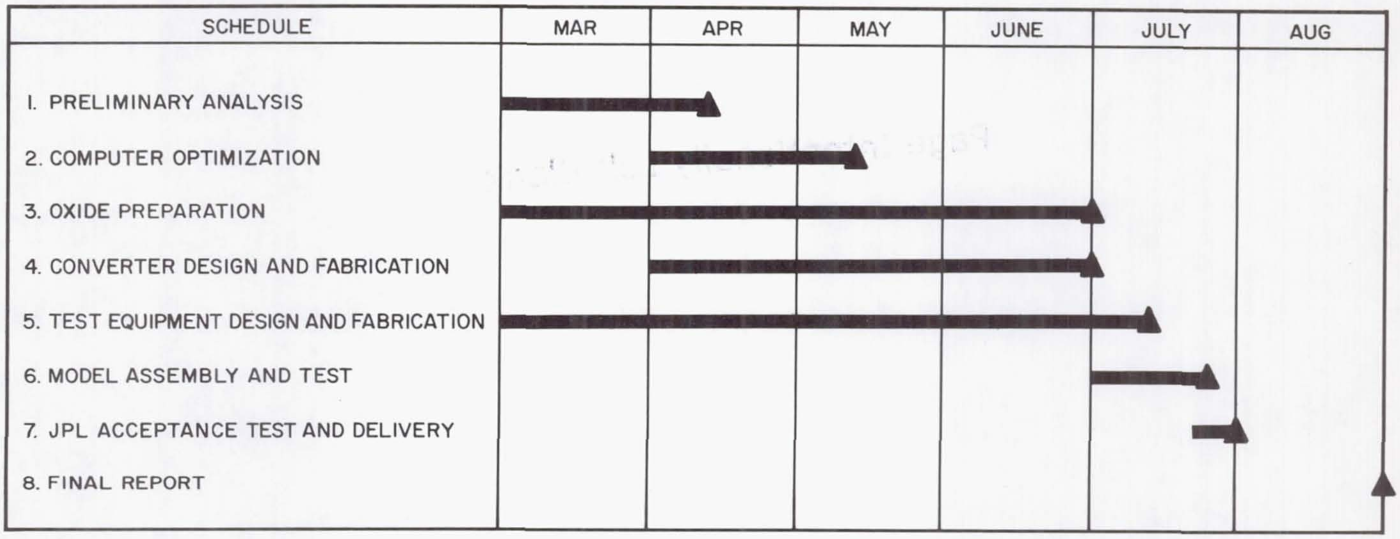


Fig. 2. TES feasibility model schedule

Work has also progressed in the design of the various test apparatus required on the preparation of individual oxide specimens for the various tests. Multicompartment crucibles have been fabricated with tungsten for use in a differential thermal analysis feasibility test of the two materials.

Figure 3 indicates the major milestones to be accomplished during this effort; at this time no significant problems have been encountered which will cause an alteration of this schedule.

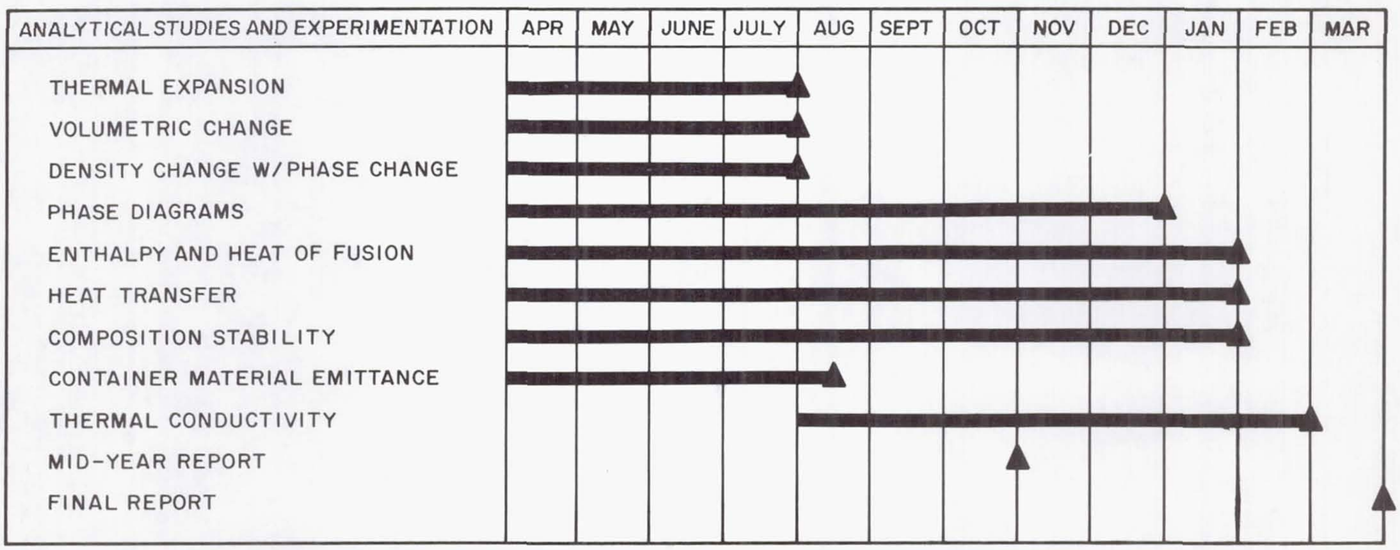


Fig. 3. Battelle Memorial Institute thermal energy storage supporting research schedule

Page Intentionally Left Blank

ELECTRIC CONVERTER ADVANCE DEVELOPMENT
NASA Work Unit 123-33-08-01
JPL 323-30301-2-3420

LOW VOLTAGE CONVERSION

One of the major problems associated with low voltage conversion is that of obtaining devices that can efficiently convert the very low voltage, high current power available from the newer sources, such as a thermionic generator, to the high voltage lower current requirements of spacecraft electronic device. Germanium power switching transistors have been used in the laboratory. These are not always suitable for spaceflight operations, however, because of their temperature limitations and slow switching speeds. Out-of-house developments of two different types of switches have been initiated as a solution to this problem. One is the development of a high power, low saturation voltage silicon switching transistor to be used with both well-known and newly developed solid-state converter techniques. The other is the development of a high temperature, zero-drop cesium vapor thyratron operating with cavity thermal power and associated converter circuitry. In-house work will involve development of efficient low voltage converters and converter techniques using silicon transistors.

1. Device Development

   a. High Power, Low Saturation Voltage Silicon Switching Transistor.

      1) Present Status. During this reporting period two proposals for a switching transistor were received as a result of an RFP; one from Westinghouse and one from ITT Semiconductor/Shockley Laboratories. (See Table 1 for tentative specifications.) The proposals presented different approaches to the development, but both indicated that the development of a transistor with the characteristics which are required is possible. The major problem involved is low saturation voltage at a high current level. If the development is 100% successful, a significant advancement of the state of the art will have been achieved. Because of the complicated nature of the development, it was decided to undertake a parallel design effort with CPFF contracts going to both companies. This way, the chances of complete success are much greater, and two separate sources for the device may result. Negotiations were entered into with both companies, and contracts are now in preparation. The contract with Shockley Laboratories is for a 9-mo effort with a funding of $73,368, and the contract with Westinghouse is for an 8-mo effort with a funding of $40,987.

      2) Planned Activities. Actual development work will start at approximately the end of July. Options are being placed in both contracts such that if one approach appears to be definitely more successful, that company will be allowed to continue with a second phase of development, which is the production of 100 units. These units are to be used in converter development.

Table 1. Tentative specifications for high power low saturation voltage silicon switching transistors

Absolute maximum ratings:

Collector to emitter voltage (BV_{CEO})	20-v min
Emitter to base voltage (BV_{EBO})	4-v min
Collector current (I_C)	100 amp min
Base current (I_B)	15 amp min
Collector dissipation, T_C = 100°C (P_C)	150-w min
Thermal resistance, junction to case (θ_{JC})	0.5°C/W
Junction temperature range (T_J)	-65 to +175°C

Electrical characteristics: (100°C case temperature)

Characteristic	Test conditions	Min	Max	Units
Breakdown voltage (BV_{CEO})	I_C = [a]	20		v
Breakdown voltage (BV_{EBO})	I_{EB} = [a]	4		v
Collector cutoff current (I_{CEX})	V_{CE} = 10v V_{BE} = [a]		[a]	ma
Emitter cutoff current (I_{EBO})	V_{EB} = 4b		[a]	ma
DC current gain (h_{FE})	I_C = 75a V_{CE} = 1v	20		
Saturation voltage ($V_{CE(SAT)}$)	I_C = 75a I_B = 5a		0.2 (see note b)	v
Saturation voltage ($V_{BE(SAT)}$)	I_C = 75a I_B = 5a		1.4	v
Total switching time ($t_d + t_r + t_s + f_f$)	I_C = 75a I_B = 5a V_{BE} = -1.5v on turnoff		15	μsec

[a]Manufacturer's standard specifying procedure acceptable.

[b]A saturation voltage of 0.1-v under the above conditions shall be a design goal.

[c]Device is to be used in dc-to-dc converter of parallel configuration. Duty cycle is 50% and operating frequency may be up to approximately 5 kc. Operating conditions are either fully saturated or cut off.

b. High Temperature Zero Drop Thyratron Development. A statement-of-work was generated and requests for proposal were sent to several companies known to be active in the thermionic and electrical converter areas. The development consists of two phases. Phase I is a 3-mo study that establishes design criteria, electrical parameters and figures-of-merits for the thyratron and its associated converter. Phase II is the design and evaluation of the thyratron and converter and is a 9-mo effort. Following is a list of the required characteristics for the thyratron.

Forward current	100 amp
Forward blocking voltage	20-v
Forward drop during conduction	0.1-v
Forward current in blocking condition	0.1 amp
Reverse leakage current	0.1 amp

Gating requirements and switching time - To be determined in Phase I.

The associated dc-dc converter must operate from a voltage source of 3-v maximum and produce a minimum of 150-w output at 28-v nominal.

2. Circuit Development

a. Present Status. Nominal design studies have begun for a breadboard low input voltage converter using silicon switching transistors. The best available silicon switching transistors that are suitable for the development have been ordered. The converter will operate at approximately the 50-w level from a 2- to 3-v source and will be used to study techniques to be used when the transistors described above become available. Efficiency of the breadboard will be moderately low because of the fairly high saturation characteristics of presently available silicon transistors, but techniques for conversion and regulation from a low voltage source can still be developed.

b. Planned Activities. Design and construction of the breadboard should start in the next quarter. Modification to study different techniques, and evaluation of the various techniques should extend through the next fiscal year.

SWITCHED REGULATOR STUDY

A goal of this in-house study is to develop improved techniques for switched regulator design. These techniques include open loop input compensation, and mag-amp drive of the power switch. It is also a goal to raise the power level of the switched regulator. Switched regulator output transients, caused by line changes, are excessive and input compensation should reduce them. High power capability requires the paralleling of power transistors. Mag-amp pulse width modulation is used because it results in a small parts count, and isolation between the control and output is easily achieved. Specifications were generated (Table 2), and a regulator designed and breadboarded. Figure 1 is a block diagram of the regulator.

Table 2. Design specifications for 400-w regulator

Input voltage, v	25 to 70
Output voltage, v	20
Load, w	40 to 400
Operating temperature, °C	-10 to +75
Regulation, %	±1
Ripple, v	<0.2 peak-to-peak
Turn-on transient, v	<2 overshoot
Line and load transients, v	±2 for 50 msec
Efficiency, %	85 for load >200 w

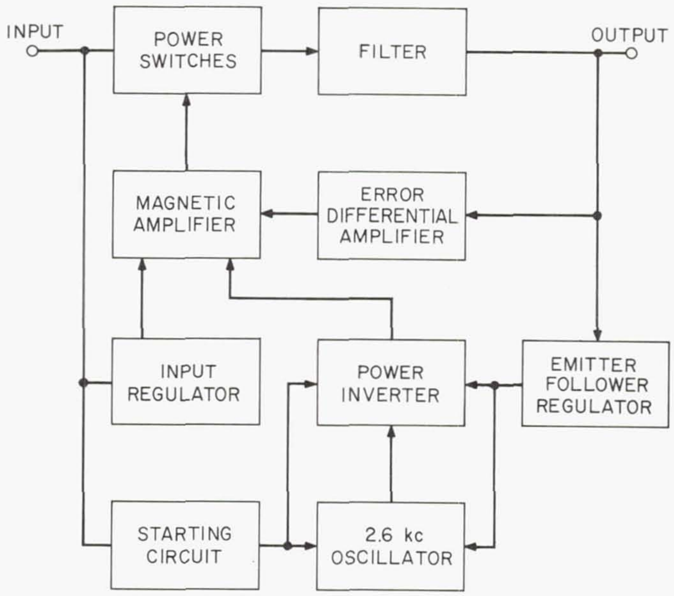


Fig. 1. Diagram of 400-w switched regulator

1. Present Status

Tests results demonstrated satisfactory design with few deficiencies. Loop stability and regulation were quite adequate. Long switching rise time due to slow base drive turnon yielded slightly low efficiency. Transient response to a load change is excessively long due to larger storage time of the switching transistors under light load conditions. A detrimental side effect was observed in the test; the switching transistors will be damaged if an output short occurs. All of these problems are described more fully in SPS 37-31, Vol IV.

Design modifications were incorporated to correct these problems. The switching transistor base drive circuitry was redesigned for shorter storage time and faster rise time. Design of a short circuit protected regulator was investigated.

2. Future Work

This effort is to be completed during the next six months. Conformance to the design requirements will be demonstrated. The breadboard will be modified for short circuit protection followed by testing and a final report.

COMPUTER WORST-CASE ANALYSIS

The Computer Worst-Case Analysis effort is being pursued in order to develop an in-house capability of worst-case circuit analysis for both new and existing designs. JPL's transient analysis generator (TAG) program is being utilized for these purposes. Mesa Scientific Corporation has been contracted to aid in the development and application of equivalent computer models of nonlinear circuit elements.

1. Present Status

A procedure for the evaluation of transistor static parameters has been developed and an evaluation of a 2N1016 transistor made. Families of input and output characteristic curves for the 2N1016 were prepared using the Ebers-moll model. (See Fig. 2 and 3.) A similar procedure for evaluating diode parameters was tried using a Linville Single - L diode model. This is a model developed by Mesa Scientific Corporation which offers improvement over the Ebers-moll model in dynamic fidelity. Actual reverse recovery time measurements were made for three diode types and compared with the single L model results. Good agreement was obtained. A simple nonlinear core model has been programmed and successfully run. A more sophisticated core model has been developed and is undergoing program debugging.

Experimental analysis runs have been made in order to explore TAG as a circuit analysis tool. To test the accuracy and efficiency of TAG, an RC ladder network of n sections was selected (see Fig. 4). Solution runs of 1, 2, 3, 5, and 10 section ladder networks were made. The results of these runs were compared with hand calculations. The comparison showed good correlation between the two methods. A complete set of dc solutions to a three-stage amplifier has been completed employing Ebers-moll nonlinear models for the transistors.

3. Planned Activities

It is planned to finish the magnetic core model and make computer runs to validate it. The relative advantages of the Linville transistor models will be investigated. JPL engineering personnel will be instructed in the use of TAG as an aid to worst-case analysis.

SOLID STATE SWITCH DEVELOPMENT

The purpose of the solid state switch development is to replace an existing motor-driven power transfer switch with its attendant problems of weight, size, external field, cost, reliability, and delivery. The circuit (Fig. 5) is a hybrid approach; that is, a transistor circuit handles the turn on-off transients and limits the voltage across an associated pair of relay contacts during contact transfer to three volts or less. The relay contacts (relay K2, contacts 2-4) are closed for the steady state load and provide a minimum voltage drop.

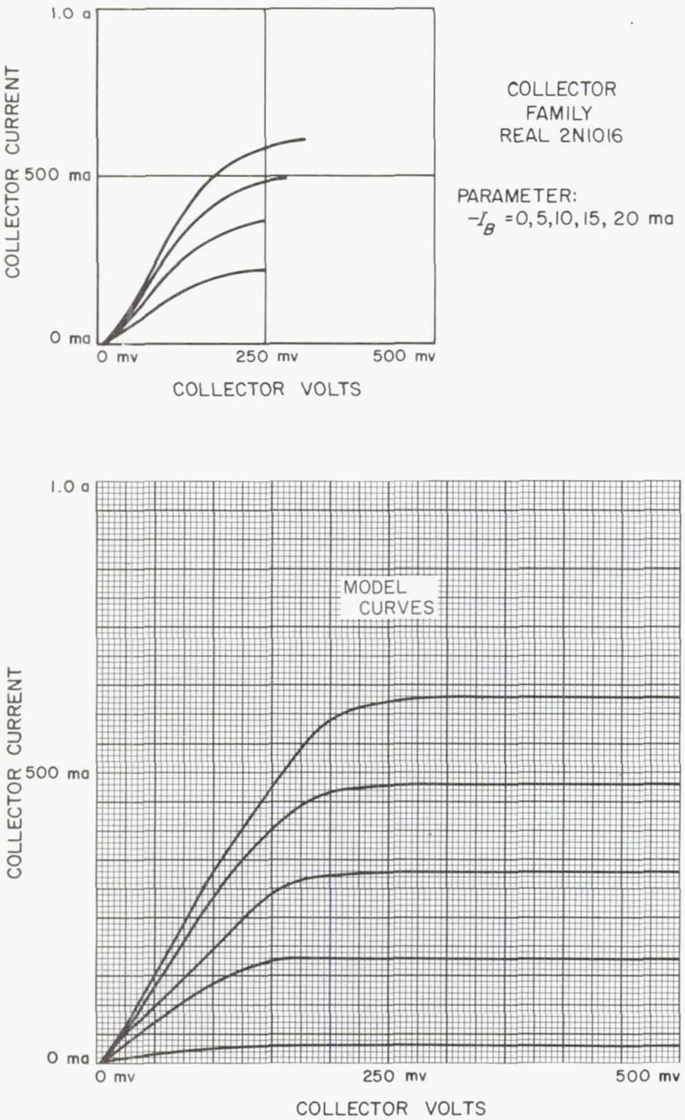


Fig. 2. Collector input-output curves

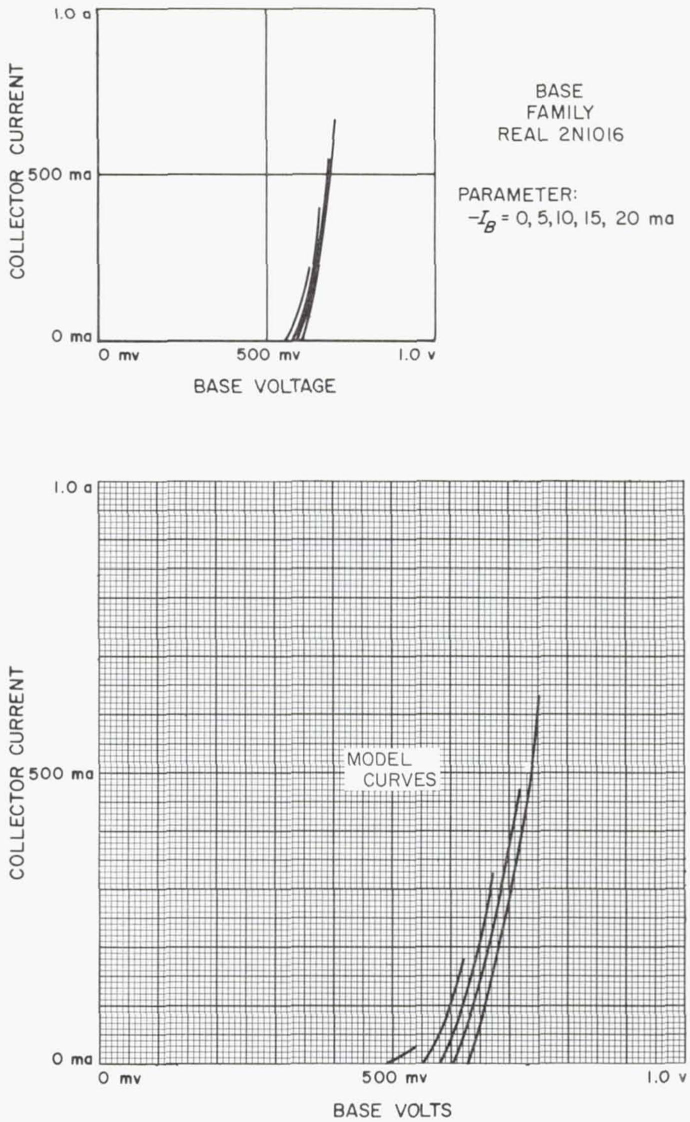


Fig. 3. Base input-output curves

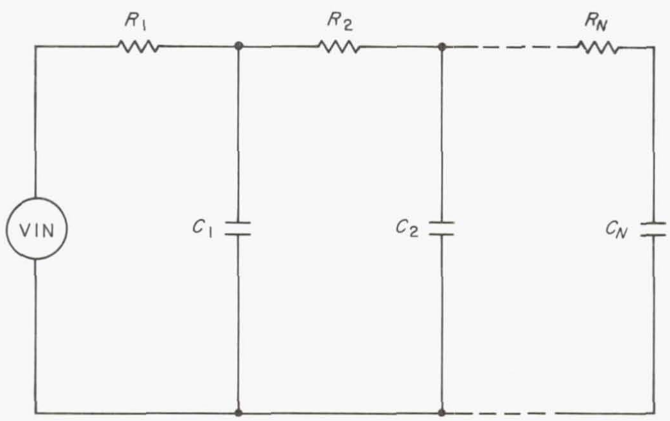


Fig. 4. N-section RC ladder network

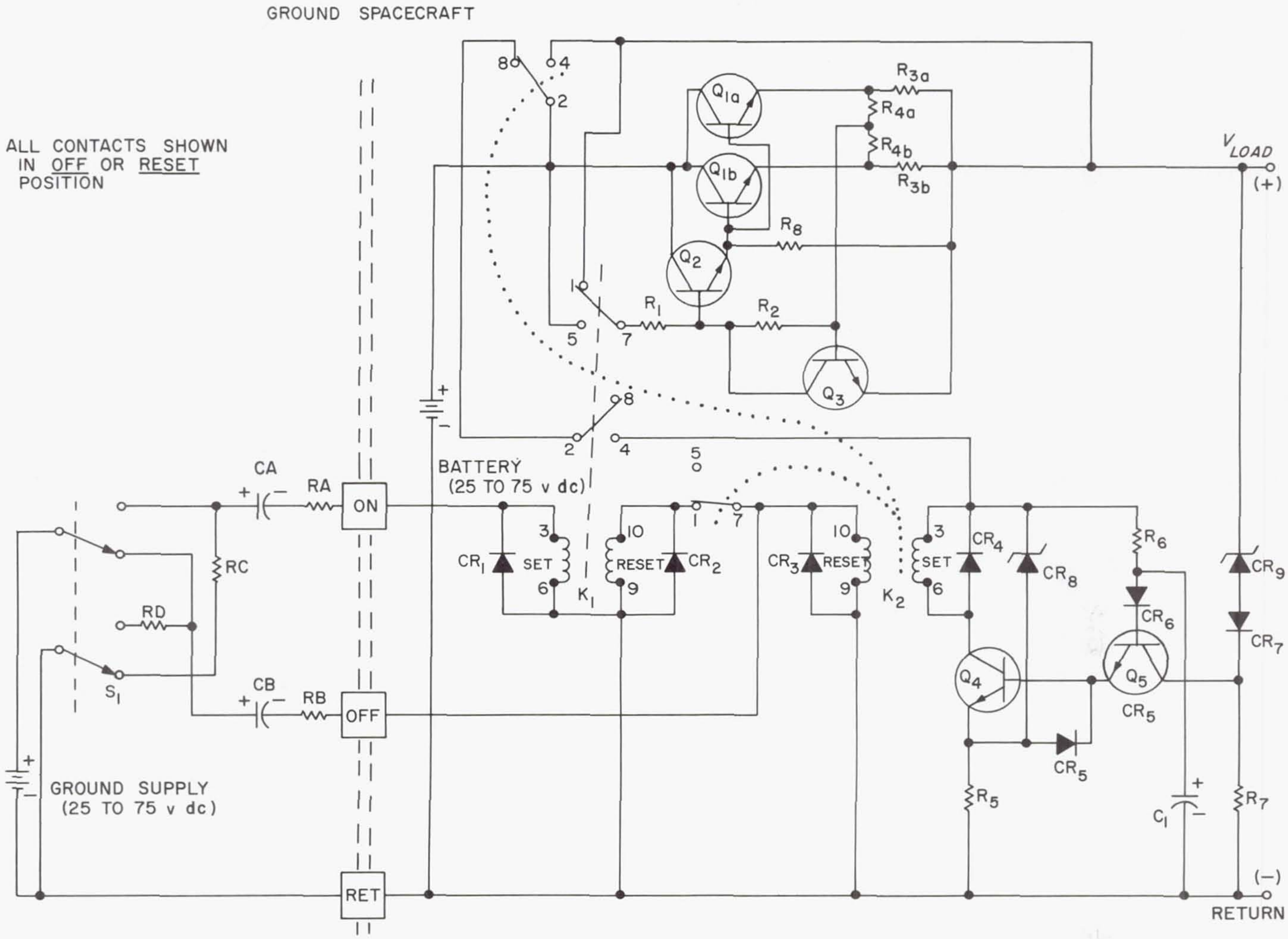


Fig. 5. Hybrid solid state switch schematic diagram

1. Present Status

A hybrid solid state switch has been designed and constructed from which test results have been obtained at -10, +25, and +75° C. This design was completed using only high reliability components; then optimized for efficiency and reliability, with effort made to reduce the total number of components used. A worst-case analysis was performed to guarantee performance over the temperature range of from -10 to +75° C. The test conditions under which this information was obtained are as follows:

Ground supply = 25 v dc
Spacecraft battery = 25 v dc
Load = 20 amperes paralleled by a 400-μ fd capacitor
Cycle of operation = 2 to 5 sec per complete cycle.

Temperature (0)°	Number of cycles of operation
-10°C	1000
+25°C (room temp.)	700
+75°C	1000

There was no indication of deterioration of the switching characteristics throughout the test.

2. Planned Activities

The present configuration loads the battery slightly in both the off state and on state. It is planned to change the configuration so that the switch is a load only during transition and represents no load while in steady state on or off condition.

CHEMICAL POWER GENERATION (123-34)

ENERGY STORAGE ADVANCED DEVELOPMENT
NASA Work Unit 123-34-01-01
JPL 323-40101-2-3420

RADIATION EFFECTS ON BATTERY ELECTRODES

1. Ni-Cd System

Atomics International Contract 950514, "The Effects of Radiation on Nickel-Cadmium Electrodes," has been completed. Pairs of nickel and cadmium electrodes in flooded cells were exposed to large doses of gamma radiation ranging from 10^6 to 10^8 rads. The effect on cell potential was negligible. Permanent damage appeared as partial electrode disintegration and loss of cadmium-electrode capacity and was significant. Capacity loss was permanent in that cells could no longer be charged to full capacity. Figure 1 illustrates the effects at different average states-of-charge.

Electrode disintegration is not large but could be important. Material is lost whether or not the cell is cycled, although the amount is smaller where no cycling occurs. Virtually all of the material comes from the cadmium electrode. Figure 2 shows the effect of irradiation at 75% of full charge.

A manuscript is being prepared for publication covering this work.

2. Ag-Zn System

Contract 951109 was let to Atomics International on March 13, 1965, for the study of the radiation effects on silver oxide and zinc electrodes. Only preliminary work has been done at this time; however, the zinc electrode will pose a major structural problem initially, and there is evidence of disintegration of the silver electrode under gamma radiation.

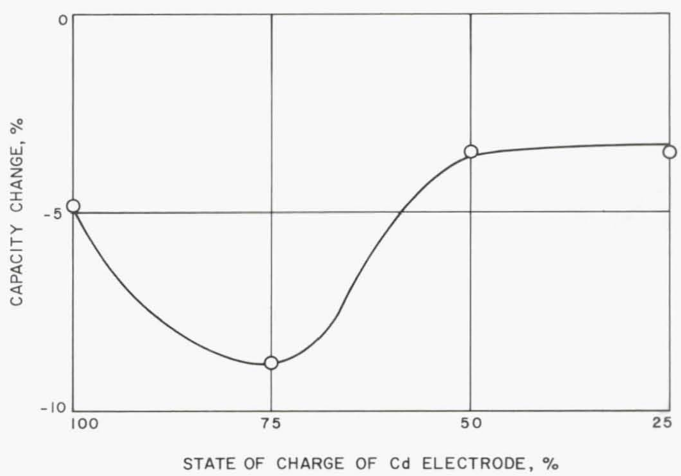


Fig. 1. Effect of radiation on maximum capacity of Cd electrode

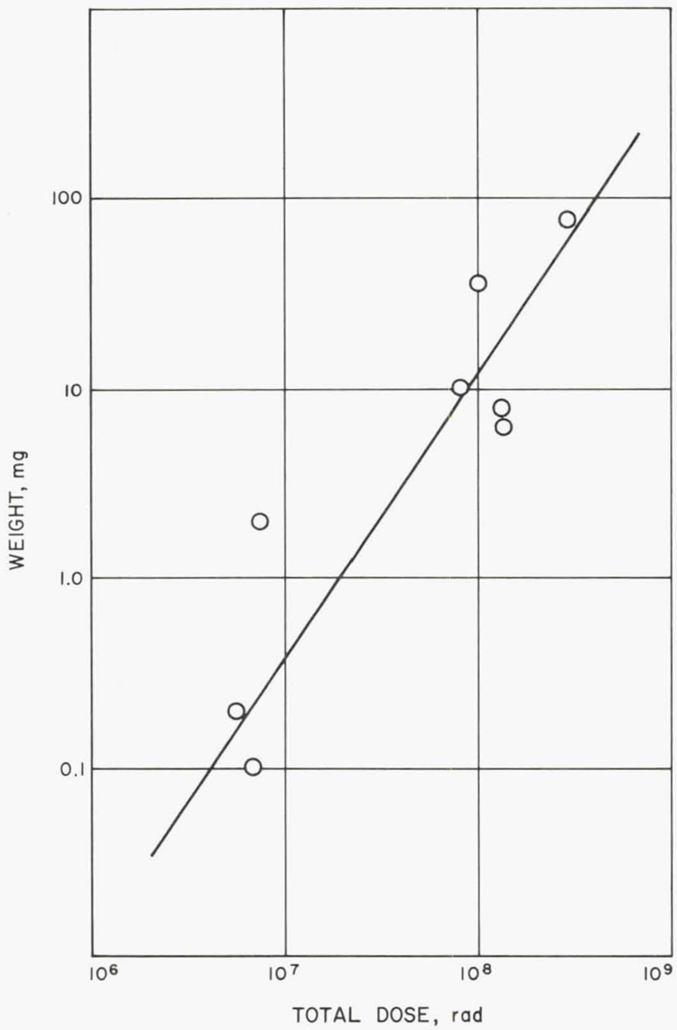


Fig. 2. Material loss as a function of radiation dose

This contract will require extension for at least one year.

3. Radiolysis of KOH Solutions

Dr. James King of JPL is studying the radiolysis of various concentrations of KOH in water in support of the electrode study. Carefully purified and degassed samples of 0.5% KOH have been irradiated under an atmosphere of helium in an attempt to duplicate some early experiments performed by Atomics International. Gas analyses showed that only small amounts of hydrogen (less than 1%) and no oxygen were formed. This is in contrast to the 22% hydrogen and 12% oxygen reported by Atomics International.

This work will be continued to cover concentrations of KOH up to 30%. Elucidation of a reaction mechanism will be attempted.

REACTION GEOMETRY OF THE SILVER ELECTRODE

Purchase Order AE 4-310901 with Brigham Young University terminated in January; the work is continuing under Contract 951157 which began February 26.

Constant potential studies were made at a charging voltage just sufficient to cause oxidation of Ag to Ag_2O. The current variation with time is shown in a typical curve (Fig. 3). The behavior has been difficult to reproduce; plates made by different companies show widely varying characteristics. Pretreatment of the electrodes is critical.

Results of constant-current charging experiments were erratic. Oxidation does not occur preferentially at the electrode surface if the electrolyte solution has been allowed to penetrate the plate pores. Regions of unreacted silver were found completely surrounded by Ag_2O. The observation suggests that Ag_2O acts as an insulator to prevent further oxidation of the metal.

Some experiments indicate that Ag(II) in HNO_3 absorbs light at 412 ±5 millimicrons. A method of determining Ag(II) in the presence of Ag(I) and Ag is being investigated.

Further work will necessitate preparation of special sintered silver plates and the chronopotentiometric study of the electrode reaction in order to reduce uncontrolled variables.

THERMAL BATTERY

As planetary probes reach greater distances and as landing requirements are imposed upon them, batteries capable of withstanding long "stand life," sterilization, and shock become more important. The thermal battery may be suitable for such missions if it can be made to operate over fairly long periods. PR 375118 was issued for the development of an experimental battery which would deliver 200-w at 20-v for 2 hr at an ambient temperature as low as 0° C. The battery would not be expected to fly nor is the development directed toward any specific mission.

GRAVITY EFFECTS ON ELECTRODE BEHAVIOR

Until recently, all acceleration experiments were made with electrodyte solutions saturated with ZnO initially. Figure 4 shows the results of those trials in which

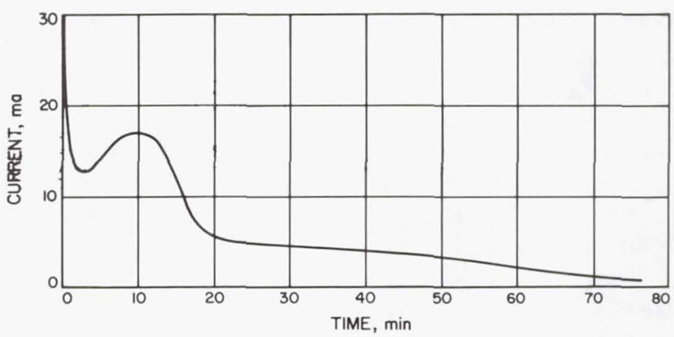


Fig. 3. Effect of charging silver electrode at constant voltage

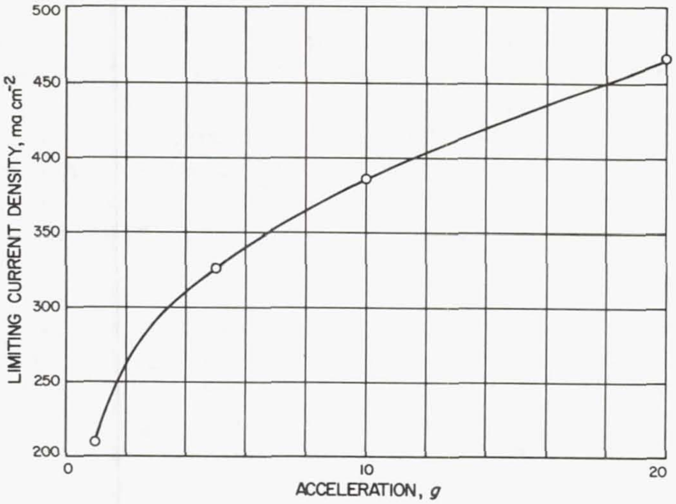


Fig. 4. Effect of acceleration on electrode when electrolyte initially contains no ZnO

the KOH solution contained no ZnO. The general shape of the curve is similar to those obtained previously, but the magnitude of the limiting current densities are considerably greater. Solutions which are about 0.5 F Zn(II) are being used in current experiments.

PR 375127 has been issued for the design of a flight package to study the effects of accelerations less than that of Earth gravity. The package is to be completely self-contained except for telemetry.

THERMAL DECOMPOSITION OF AgO AND Ag_2O

Powdered silver oxides were heated in air at 135°C. The samples were cooled and weighed periodically to determine weight loss. The following reactions are assumed to occur:

$$2AgO \text{ --- } Ag_2O + 1/2O_2 \qquad (1)$$

$$Ag_2O \text{ --- } 2Ag + 1/2O_2 \qquad (2)$$

AgO loses half of its available oxygen during the first 24 hr. Subsequent decomposition can be attributed to Ag_2O as can be seen by comparing the slopes of the curves in Fig. 5 and 6.

Ag_2O decomposes more rapidly in an open crucible than in a covered crucible. The reaction is known to be reversible at higher temperatures (300°C) and may account for these observations. The magnitude of the effect seems too large to be attributable to reversibility, but no other mechanism can be suggested at this time.

Continuing studies should include investigation of effects of particle size, controlled atmospheres, and photochemical phenomena. In all cases, weight changes should be monitored continuously.

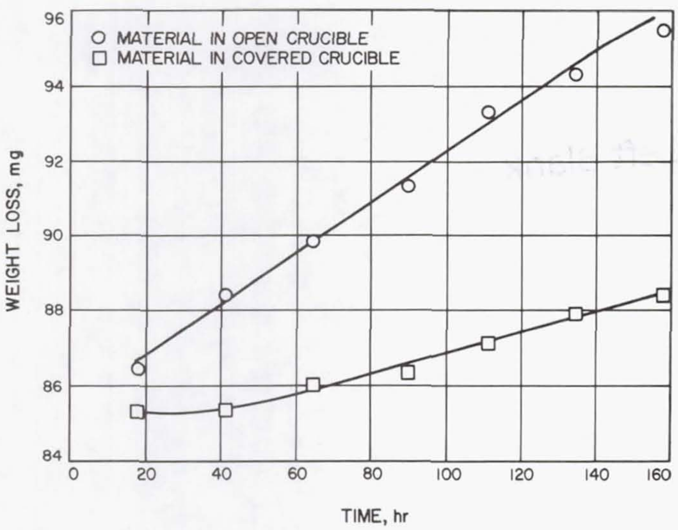


Fig. 5. Decomposition of AgO at 135°C

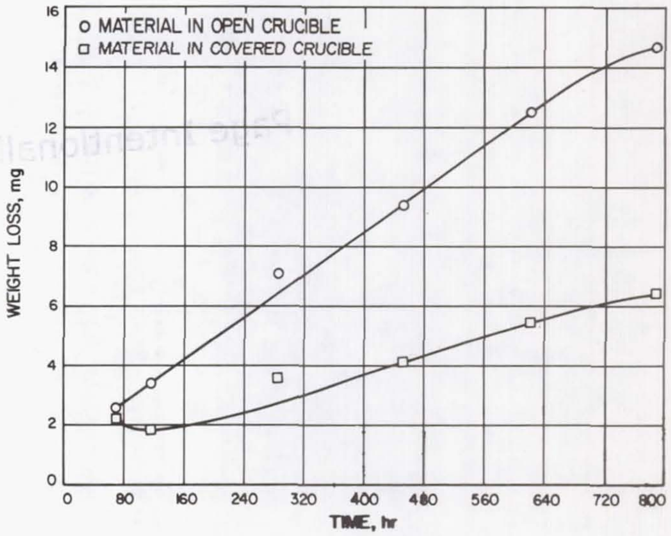


Fig. 6. Decomposition of Ag_2O at 135°C

STATE OF CHARGE

The state of charge of the nickel-cadmium cell was to be monitored simply by adding a convenient quantity of tritiated water to the electrolyte solution and following the change of tritium content with a liquid scintillation counter. The simple procedure is not practical because the total count-rate change is only about 5% as the cell changes from the fully charged to the fully discharged condition.

Some fundamental electrode and material studies are necessary if the tracer method is to be made feasible. The rate of exchange of tritium between water and insoluble hydroxides must be determined. The rate of water utilization by the electrodes must be known. Finally, the optimum sampling method must be determined. Plans for implementing solutions to these problems will be completed in early FY 1966.

Page Intentionally Left Blank

ADVANCED CONCEPTS (124-06)

ADVANCED PLANETARY AND LUNAR SYSTEMS ANALYSIS
NASA Work Unit 124-06-01-01
JPL 324-60101-2-3120

NAVIGATION AND MANEUVER ANALYSES FOR BALLISTIC TRAJECTORIES

Orbit Redetermination

General analytical techniques for use in premission orbit determination studies have been formulated and applied to the near-Earth orbit redetermination problem as discussed in JPL internal reports on the analytical approach to premission orbit determination studies and orbit redetermination following the first midcourse maneuver. Specifically, an analytical investigation of the orbit redetermination process following the first midcourse correction on an interplanetary trajectory is developed. A simple model employing straight-line motion of the spacecraft is developed and used to derive analytic expressions for the partials of doppler data with respect to the quantities to be estimated, in this case the velocity components of the spacecraft following the maneuver. The possible effects that contribute to these partials are discussed, and their relative importance in the orbit determination process is investigated. It is shown that the motion of the observing stations, due to the rotation of the Earth, is the dominant effect which determines the magnitude orbit-determination uncertainties. These results are corroborated by evidence from past studies on the orbit-determination program (ODP) that display a correlation between poor orbit redetermination knowledge and small declinations of the outgoing asymptote of the near-Earth trajectory.

Figure 1 displays the dependence of the orbit redetermination process upon the declination of the outgoing asymptote of the near-Earth trajectory. In particular, the JPL orbit determination program was employed to simulate the real-time tracking process necessary to redetermine the spacecraft's orbit following the first midcourse maneuver. This program furnished estimates of the trace of the covariance matrix (1σ uncertainties) of the probe's velocity components immediately following the maneuver.

These estimates were compiled as a function of different tracking intervals for 10 different interplanetary trajectories with various declinations of the outgoing asymptote. It was assumed that the midcourse maneuver occurs 5 days after launch; and estimates of the covariance matrix were presented for tracking up to 10, 20, 30, and sometimes 50 days after launch. Figure 1 displays the square root of the trace of the covariance matrix as a function of time for three 1969 Mars trajectories. Figure 2a presents this same data, except that $\sqrt{\mathrm{trace}\ \Lambda_V}$ is now shown as a function of the absolute value of the sine of the outgoing asymptote declination for the three different tracking periods. Figure 2a clearly suggests a strong correlation between the orbit redetermination capability and declination of the near-Earth asymptote. Figure 2b presents data from seven Mars trajectories, one representative of each launch period from 1964 to 1977 inclusive. The data are presented in the same format as Fig. 2a, that is, $\sqrt{\mathrm{trace}\ \Lambda_V}$ as a function of $|\sin(\mathrm{DEC})|$ for different tracking periods. Figure 2b displays the same correlation, particularly after tracking to 20 and 30 days after launch. The plots of the numerical results from ODP

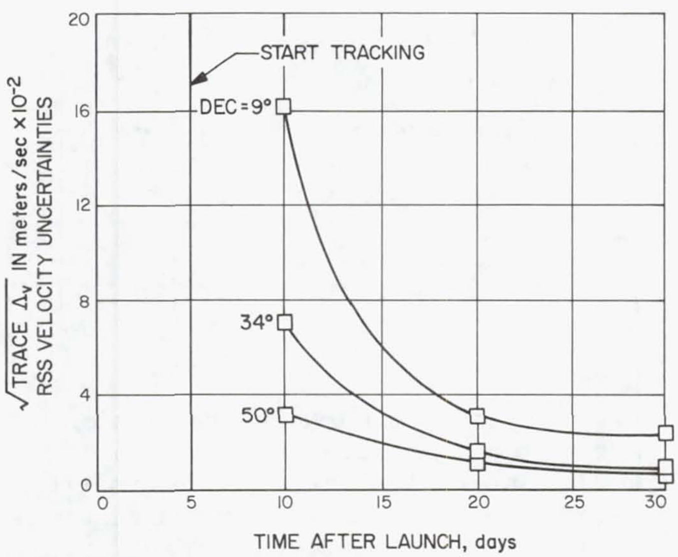


Fig. 1. Mars trajectories 1969 as a function of time

corroborate an earlier analysis that predicted the above correlations, including the poor orbit redetermination knowledge obtained on interplanetary trajectories with small declinations.

This work will be extended in the next 6 mo. The proposed extentions include a computer program utilizing the techniques of the use of hecon to design elliptical trajectories for exploratory probes (as specified in a request for proposal) to provide accurate prediction of near-Earth orbit redetermination knowledge for a large class of trajectories, and extention of the analytical techniques to handle general (non-near-Earth) orbit determinations.

Approach Guidance Orbit Determination from Earth-based Doppler Data

The properties of a near-planet or near-Moon hyperbola have been exploited to analytically develop the orbit determination equations for the approach phase of flight, assuming that single-station Earth-based doppler data are employed, and that the direction of the Earth remains constant during the entire approach phase. These equations have been coded radio approach guidance, Earth-based (RAGE) program and the program has been checked out. Studies are under way to compare results obtained with the JPL orbit determination program, and to accomplish a parametric study of some VOYAGER-type of mission. Since the RAGE program can only obtain an estimate of five orbital elements (the "binary star problem"), an analysis of the unknown element has been carried out, in particular, a technique for obtaining its estimate and error variance from the a priori statistics has been developed.

An RFP extending the RAGE program to analyze the continuous form of the estimate has been completed and programming is under way.

Approach Guidance Studies

There are several relatively distinct phases to this study and the progress associated with each phase will be discussed in order.

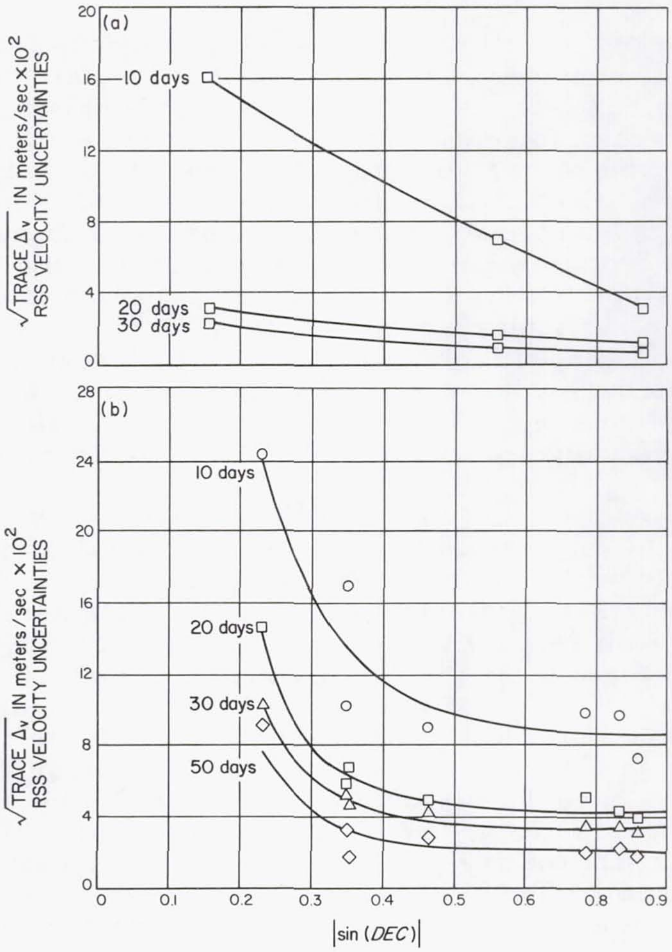


Fig. 2. Mars trajectories: (a) 1969 as a function of the absolute value of the sine, and (b) seven as a function of the absolute value of the sine, 1964 to 1977

Earth Moon Transit Phase. The results of a study of the radio-command guidance of a vehicle during transit to the Moon is nearly completed. This study considers both 66- and 90-hr transit trajectories and includes the effects of various systematic errors such as tracking station location errors on the determination of the orbit of the vehicle. This study is using recently completed programs called ODTAPP, as set forth in engineering document on the ODP, Monte Carlo/digital interface computation that enables the ODP to supply a data tape for the Monte Carlo midcourse and terminal guidance program (TAPP II). The results of this phase of the study will be the generation of covariance matrices describing the position and velocity of the vehicle at the sphere of influence of the Moon. These results will include both one and two midcourse maneuver models.

Lunar Approach Phase. A study of this phase is also nearly completed. This phase involves the determination of the path of the vehicle when near the Moon for different types of circumlunar approach paths, that is retrograde, direct or polar trajectories. The results of this study will indicate the accuracy of the determination of the path of the vehicle prior to a retromaneuver into orbit. An IBM 1620 program is being used to provide the results for this phase. An internal section memo is currently being written describing the results to date.

As an example of the accuracy of the determination of the trajectory of a vehicle near the Moon, consider Fig. 3 for a 66-hr transfer trajectory which has a distance of closest approach to the Moon of 100 km. In this figure, the one-sigma dispersion ellipse is shown for each of four different trajectories representing a pass over either pole and retrograde and direct passes at minimum inclination to the lunar orbital plane. Each of these four trajectories have identical energy and magnitude of angular momentum. The transfer phases of these four trajectories are so nearly similar from the Earth to the sphere of influence of the Moon that for all practical purposes the dispersion ellipses at the sphere of influence of the Moon are identical. For the particular example presented the semi-major and semi-minor axis were 25 and 10 km respectively at 8 hr prior to closest approach with the major axis aligned normal to the orbital plane of the Moon, these values being representative of current Ranger values. The tracking accuracy assumed in preparing this figure corresponds to a value of 0.03 m/sec for a 60 sec sample time.

Figure 3a presents the dispersion ellipses at 120-min prior to closest approach. Note that the major axis for the minimum inclination trajectories has decreased only slightly while the major axis for the polar trajectories has decreased by about 30%. This decrease reflects the fact that the plane of motion of the vehicle is changing direction with respect to the viewing station on Earth. On the other hand, the plane of motion of the vehicle for the minimum inclination trajectories does not change significantly until just prior to closest approach. Figure 3b at 85-min prior to closest approach now shows the polar trajectories with almost circular dispersions with semi-axes something less than 10 km. The major axes for the minimum inclination trajectories have decreased only slightly while the semi-minor axes are now around 6 km. Figures 3c, d, and e show the dispersion ellipses at 60, 30, and 15 min prior to closest approach respectively. At 30 min prior to closest approach, Fig. 3d, the major axes for the minimum inclination trajectories are still nearly their original value, however the semi-minor axes have decreased to less than 1 km. On the other hand, the semi-major axis of the dispersion ellipse for the polar trajectories has decreased to around 8 km and change orientation by nearly 90 deg from its original direction. Figure 3e shows the dispersion ellipses at 15 min prior to closest approach. Note in this figure that the paths of the polar trajectories are determined most accurately at this point, the semi-major axis being 4 km for the trajectory passing over the North Pole and about 2.5 km for the one passing over the South Pole of the Moon. Contrarywise, the semi-major axes are still relatively large for the remaining two trajectories, being about 19 km for the direct trajectory. It should be noted, however, that the major axes in all cases are aligned approximately normal to the radius vector at closest approach, so that the error in distance in closest approach is determined primarily by the semi-minor axis which, in all four cases, is very small at this point. The large semi-major axis of the dispersion ellipse for the minimum inclination trajectories thus represents an error in the determination of the inclination of the approach hyperbola to the orbital plan of the Moon.

Retromaneuver Phase. An IBM 1620 Monte Carlo was written in 1964 to investigate this particular phase of the mission. This program is currently being modified for the new IBM 1620 Mod II computer which is being used. In this modified program the statistical accuracy of the lunar orbit obtained after the first maneuver will be described. This study will include the effects of trajectory errors, orbit estimation errors, and maneuver execution errors. A Fortran subroutine which generate nearly normally distributed random numbers with zero mean and unit standard deviation has also been written for the above program.

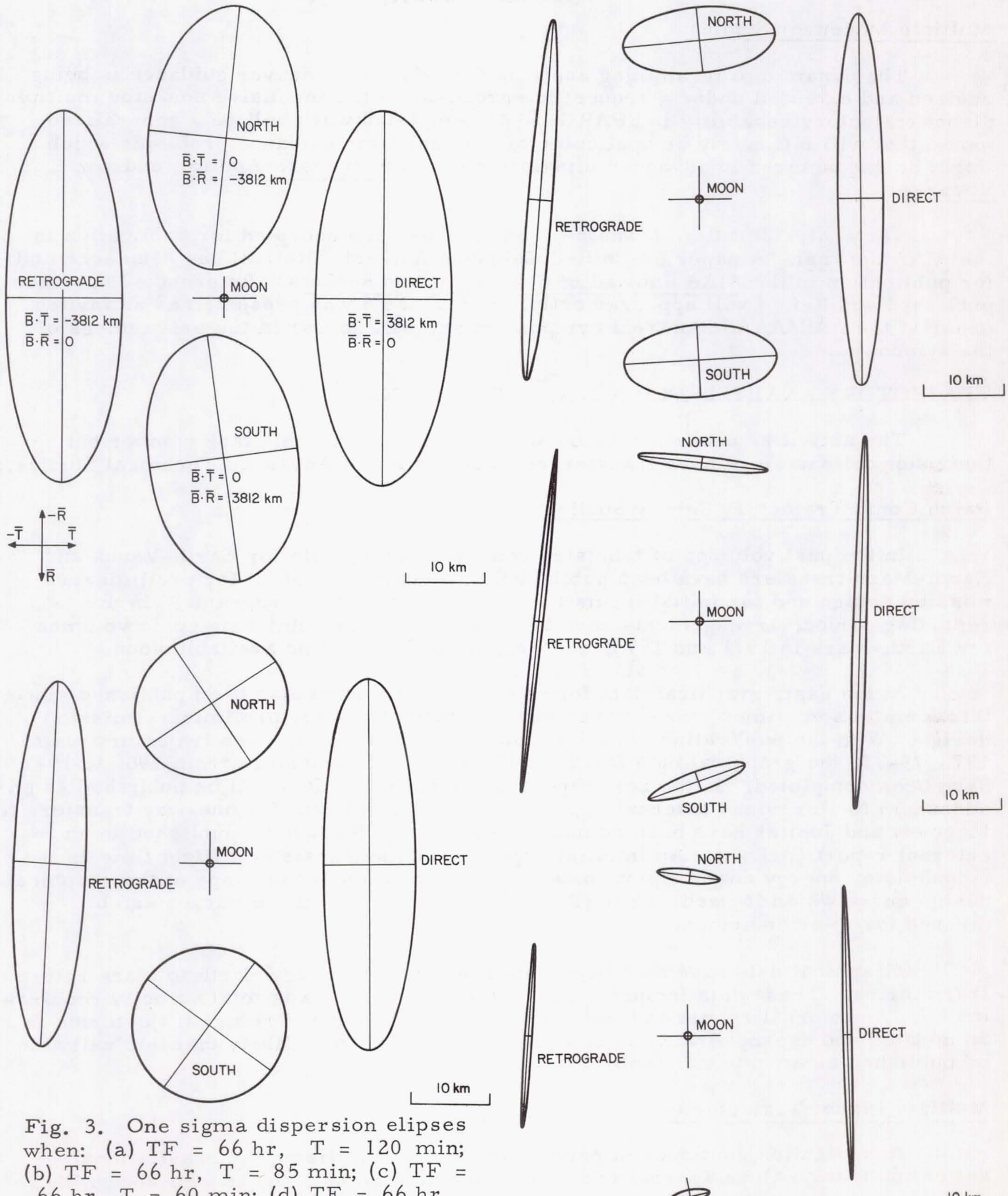


Fig. 3. One sigma dispersion elipses when: (a) TF = 66 hr, T = 120 min; (b) TF = 66 hr, T = 85 min; (c) TF = 66 hr, T = 60 min; (d) TF = 66 hr, T = 30 min; and (e) TF = 66 hr, T = 15 min

Multiple Maneuver Studies

The dynamic programming analysis for missile maneuver guidance is being revised and extended under a request for proposal on the impulsive non-stop multiple planet trajectory capability in SPARC. The completed work will be a generalized model that will ultimately be applicable to the real-time guidance problems which might be encountered in advanced missions such as Surveyor, Apollo, and Voyager.

The analysis of Ref. 1 was revised and has been accepted for publication in the AIAA Journal. A paper on Unified Guidance Analysis (Ref. 2) has been accepted for publication in the AIAA Journal of Spacecraft and Rockets. Reference 3 has been published and Ref. 4 will appear shortly. Reference 5 was presented as an invited paper at the AAS/AAAS Montreal Symposium and will appear in the proceedings of the symposium.

TRAJECTORY ANALYSIS FOR ADVANCED MISSIONS

The activities described below were initiated under this task number but their support has since been transferred to the Office of Advanced Technical Studies.

Patch Conic Trajectory Survey Studies

In the past volumes of tabulated conic trajectory data for Earth-Venus and Earth-Mars transfers have been published. The data are useful for preliminary mission design and for initial inputs for precision targeting programs. In this reporting period, arrangements have been completed for publishing conic volumes for Earth-Mars in 1971 and 1973, and Ref. 6 and 7 should be available soon.

In the past, graphical data for conic transfers have also been published since this form is sometimes more convenient than tabulations for preliminary mission design. With the publication of an internal report on Type II Mars trajectory plots 1973-75-77, the graphical data for Type II Earth-Mars transfers from 1966 to 1977 have been completed. In the next reporting period these data will be published as an addendum to a previous external report. The graphical data for one-way transfers to Mercury and Jupiter have been completed and these will soon be published in an external report (Ref. 8). An internal report on the synthesis of a flight time vs launch date, energy contour plot contains an explanation of the shape of the graphical design curve which is used, while (Ref. 9) illustrates how these curves can be utilized for mission design.

Graphical data have also been obtained for high energy Earth to Mars return trajectories. These data include stopovers at Mars and gives total velocity requirements. An internal report on high energy Earth to Mars and return trajectories is an updated and expanded version of a previous memo. It is likely that this will also be published as an external report.

Multiple Planet Trajectories

Investigation continues of promising missions utilizing the gravitational deflection from a close approach to an intermediate planet. As is well known, these

trajectories often result in large launch energy savings. The work reported in Ref. 10 is being continued in order to find in what years beyond 1970 there will be desireable Earth-Venus-Mercury opportunities. At present it appears that 1973 and 1978 may be good years and one may be studied in more detail.

The work reported in Ref. 11 is being continued to investigate Earth-Jupiter-probe trajectories in further detail. Also, the use of Jupiter in trips to the outer planets will be investigated.

In order to aid in the above multiple planet studies, a new computer program has been specified as noted below under computer program development.

In addition to the purely ballistic flybys mentioned above, there is also interest in flybys in which an impulse is applied near closest approach to a planet. This type of transfer seems to have some advantages for Earth-Mars-Earth trajectories when large quantities of information must be transmitted to Earth. Inter-office memos on Earth-Mars-Earth flyby missions with ΔV at Mars and Earth-Mars-Earth trajectories with ΔV at Mars for the 1971 opportunity contain preliminary results and a request for proposal for a modified IMSC trajectory program describes a computer program to be used for further studies.

Planetary Atmospheric Entry Studies

Investigations of the velocity, acceleration, and attitude profiles of a high-speed body entering a planetary atmosphere are being conducted. These will have application to future project studies such as the *Voyager* Mars capsule. Reference 12, reported previously, has now been accepted for publication in a journal.

COMPUTER PROGRAM DEVELOPMENT

The computer program developments described below derive their primary support from project funds due to their high cost and immediate applicability to project work. They are, however, indispensible tools in AD studies and accordingly are reported on here.

Space Research Conic Program (SPARC)

Currently a new conic computer program, SPARC, is being developed since the old program had reached the point where it was very difficult to make any more additions or changes. The new program will be designed to study a number of advanced missions such as those mentioned above and also will have a structure such that new and unusual missions can be easily programmed. Desired capabilities of SPARC are listed in an interoffice memo on missions to be analyzed using SPARC. Equations have been specified for one of these capabilities in requests for proposals on: (1) one-way portion of the new version of Hecon, (2) the use of Hecon to design elliptical trajectories for exploratory probes, (3) specification for non-stop multiple planet trajectories in SPARC, and (4) impulsive non-stop multiple planet trajectory capability in SPARC. One-way and probe capability are now working and the multi-planet capability will be available within a month.

Orbit Determination

The DPODP (double precision orbit determination program) is currently being developed at JPL. This is basically a new orbit determination program rather than an extention of the single precision ODP (SPODP). This program will be used for inflight and postflight reduction of tracking data for lunar and planetary missions to solve for injection conditions and physical constants, etc., which effect the observations (primarily doppler). Although none of this development is being supported by this task, the new capabilities are important as a basis for comparing and verifying results obtained by other means.

REFERENCES

1. Pfeiffer, C. G., A Dynamic Programming Analysis of Multiple Guidance Corrections of a Trajectory, TR 32-513 (Revision 1), August 10, 1964.

2. Hamburg, R., Pfeiffer, C. G., Soong, T. T., Unified Guidance Analysis in Design of Space Trajectories, TR 32-577, January 31, 1965.

3. Pfeiffer, C. G., "Space Navigation and Guidance," Contribution to McGraw-Hill Encyclopedia of Science and Technology (to appear in 1965).

4. Pfeiffer, C. G., "Guidance Analysis," Ch. 6 of Lunar Missions and Explorations (edited by Leondes and Vance), John Wiley and Sons, 1964.

5. Pfeiffer, C. G., "Some Theoretical Considerations Arising in Guidance Analysis," presented at AAS/AAAS Montreal Symposium Towards Deeper Space Penetration, December 28, 1964.

6. Richard, R., Roth, R., Earth-Mars Trajectories 1971, TM 33-100, Vol. 4, (to be published).

7. Richard, R., Roth, R., Earth-Mars Trajectories 1973, TM 33-100, Vol. 5, (to be published).

8. Feitis, P., et al, Design Parameters for Ballistic Interplanetary Trajectories, Part II One-Way Transfers to Mercury and Jupiter, TR 32-77, Part II, (to be published).

9. Tito, D., Trajectory Design for the Mariner 1964 Mission, AIAA paper 65-516, to be delivered at AIAA 2nd Annual Meeting and Technical Demonstration, San Francisco, California, July 26-29, 1965.

10. Sturms, F., Cutting, E., Trajectory Analysis of a 1970 Mission to Mercury Via a Close Encounter with Venus, AIAA Paper 65-90, presented at AIAA 2nd Aerospace Sciences Meeting, New York, January 26, 1965.

11. Minovitch, M., Utilizing Large Planetary Perturbations for the Design of Deep-Space, Solar-Probe, and Out-of-Ecliptic Trajectories, TM 312-514, February 15, 1965.

12. Feitis, P., "Translational and Rotational Motion of a Body Entering the Mars Atmosphere," to be published in RAUMFAHRTFORSHUNG by the WGLR (German Rocket Society).

Page Intentionally Left Blank

HIGH ENERGY MISSIONS – MISSION REQUIREMENTS
NASA Work Unit 124-06-01-06
JPL 324-60601-2-2920

The initial objective of this task was to examine a number of future missions in order to determine mission requirements in terms of mission objectives and the capabilities and resources required for their accomplishment. The missions planned to be examined included an out-of-the-ecliptic mission and missions to Jupiter, Mercury, and possibly Saturn. Selection of a range of mission objectives and mission goals was to be established for each mission and contractor support was to be employed to study the alternate means of accomplishing the missions. A total of \$480,000 was to be expended for three, or possibly four industry studies.

During the first part of the study period missions to Jupiter were emphasized with secondary effort directed toward Mercury missions. Out-of-the-ecliptic and advanced asteroid missions were examined in a cursory manner. The class of Jupiter missions studied included:

1. Early flyby.
2. Orbiter.
3. Early entry probe.

The study considered a time period from 1970 to 1980 for mission accomplishment with Titan IIIC to Saturn CV, and a possible high energy kick stage as the range of available boosters. A preliminary set of scientific objectives were established and some of the major problem areas of the mission were identified for study. In addition state-of-the-art problems, tradeoff factors, and interface problems were delineated for further study.

Early in the second quarter, a report was prepared on the in-house survey study on high energy missions and forwarded to R. Wisniewski of NASA/OART. Subsequent budget review of the program lead to a decision during November 1964 that this task would be limited to a total expenditure of \$150,000 during FY 1965. In order to retain the funds necessary for one limited Jupiter mission study contract with industry, it was determined that the in-house manpower level on this task would be reduced to one man for the remainder of the year. The two other in-house people concerned with this study area during the early part of FY 1965 were reassigned to advanced mission studies for OSSA during the remainder of the fiscal year (under the task title of High Energy Missions: Generic Space Probe (Advanced Planetary Probe) and Jupiter Orbiter, NASA Code 684-30-07-01).

Revised funding allocations received during the second quarter reduced total funding to \$105,000. Due to this reduction in funding and prior in-house expenditures and industry, study was precluded and the in-house study effort was continued on a low-level to refine the mission requirements.

Two mission and conceptual design studies sponsored by OSSA: (1) Jupiter orbiter and (2) advanced planetary probe were prepared for approval and subsequent solicitation to industry. An agreement was reached by OART and OSSA to jointly

sponsor the study effort including a Jupiter flyby study. Planning for the mission studies proceeded during the PAD approval period.

Budget reviews during the fourth quarter necessitated dropping the Jupiter orbiter study from further consideration at this time. A request for proposal was prepared on the Jupiter flyby study NASA Code 684-30-09-01 and released to industry on June 6, 1965. A request for proposal was prepared on the advanced planetary probe study NASA Code 684-30-08-01 and issued to Thompson-Ramo-Woolridge Corporation for a single source procurement on the basis of their unsolicited proposal dated November 1964, and titled Deep Space Planetary Probe System.

SPACECRAFT AEROTHERMODYNAMICS (124-07)

PLANETARY GAS DYNAMICS
NASA Work Unit 124-07-01-01
JPL 324-71401-2-3530

EQUILIBRIUM SHOCK LAYER RADIATION

Analysis of equilibrium shock-layer radiation for Martian entry has continued during the last six months. Although some discrepancies between experiments from JPL, G. E., and NASA Ames are only presently being resolved, a simplified interim expression for stagnation-point, equilibrium, radiation heat transfer was developed on the basis of both experimental and theoretical information. The expression intended for JPL study purposes in the velocity range of 17 to 26 Kft/sec is

$$\frac{q_r}{R\,(10^5\,\rho\,)^{1.35}} = -13.9 + 0.692\left(\frac{V}{10^4}\right)^{7.53}$$

where q_r is the stagnation-point heat transfer in Btu/ft^2 -sec, R the equivalent spherical *nose radius in ft,* ρ *the free-stream density in slugs/ft*^{3}, and V *the flight* velocity in ft/sec. It was found that the somewhat simpler form $\rho^x\ V^y$, commonly used, is an inadequate description in the velocity range of interest, because of the particular contribution of the well-known dominant radiator, the molecule CN.

The normalization of heat transfer by the free-stream density, as in the above equation, has been examined theoretically for the Martian speed range, as reported in JPL SPS 37-33, Vol. IV, June 30, 1965. The effect of density level as a given velocity was found to be small, but the effect of velocity was sufficiently large such that uncertainties could arise if the normalization procedure is not carefully used. There is also an effect evident because of uncertainties in the energy of dissociation (D_0^o) for CN. Changing D_0^o from 8.2 to 7.5 ev (the present range of uncertainty) raised the density exponent from the 1.35 value to about 1.45, assuming a mean flight velocity of 21,000 ft/sec.

Equilibrium radiation heat transfer for Mars was discussed with NASA Ames personnel during a visit to Ames in April of this year. Continuing experimental work under JPL Contract No. 950297, modifications 1 and 2, were delayed early this calendar year because of a shock tube breakdown. When these data become available, the above equation will be recalculated.

A final analysis on equilibrium shock-layer radiation should be completed in the first half of fiscal year 1966, and a publication is anticipated.

TOTAL RADIATION HEAT TRANSFER

A competitive procurement is in process for $60,000 to compare various promising Martian entry shapes on the basis of experimental total (i. e., over the whole body) equilibrium radiative heat transfer. Effects of angle of attack are a

primary objective, with actual distributions around the body specified as secondary. The NASA Ames Research Center has provided helpful suggestions during the preparation of the work statement.

BLACKOUT DURING MARTIAN ENTRY

Cognizance has been maintained on research relating to the alleviation of blackout during Martian entry. Work at NASA Langley and its contractor, Mithras, Inc., has continued. The plasma-arc fluid-injection tests are currently being conducted by the JPL Propulsion Division and a final report is expected to be completed early in FY 1966.

LOW DENSITY HEAT TRANSFER

No significant effort in this area was accomplished during FY 1965 because of manpower diversion (see mid-year report) and the necessity to consider this area as having lower priority compared to other work.

HYPERVELOCITY LABORATORY
NASA Work Unit 124-07-01-04
JPL 324-708XX-2-3730

FACILITY OPERATION

The hypervelocity laboratory consists of a 3-in. cold pressure driven shock tube, a 6-in. arc heated shock tube capable of shock speeds to 35,000 ft/sec, a 12-in. piston driven shock tube, and a 43-in. Mach 12 shock tunnel. The two smaller shock tubes are fully operational; the large shock tube and the shock tunnel are under development.

HEAT TRANSFER STUDIES

Experimental studies of the thermal conductivity of noble gases at elevated temperatures using the 3-in. shock tube have been concluded. The results of the experiments tend to agree better with the Lennard-Jones potential theory than other theoretical approaches. A complete summary of the results are given in Ref. 1.

Stagnation point convective heat transfer studies are being conducted in the 6-in. arc heated shock tube. Tests are being performed in air and nitrogen, carbon-dioxide and argon mixtures in the stagnation temperature range of 10,000 to 15,000°K. Virtually all of the required experimental results have been collected. Analyses of the results are presently being made; a report will be published in the near future.

Measurements have been made of the total and spectral radiation from CO_2 - N_2 mixtures for flight speeds up to 47,000 ft/sec. The results at low temperatures have been used to establish the dissociation energy of CN which is the major radiator. This result reduces the present uncertainty in predicting the radiation by a factor of 5. A typical spectrum at 6500°K is presented in Fig. 1. The total radiation at density levels comparable to those believed to exist on the near planets has been found to exceed the predictions of theory by a factor of 5 at a temperature of 10,000°K. This result is evident in the 0.25-mm-Hg data of Fig. 2. These results will appear in the AIAA Journal (Ref. 2).

The effect of large Argon content in mixtures of CO_2 - N_2 has been investigated. Addition of 30% Argon causes a factor of 3 increase in the total radiation at a flight speed of 40,000 ft/sec. A method of correlating the radiation from any CO_2 - N_2 mixture as a function of CN number density and temperature has been developed (see Ref. 2). This allows prediction of the radiation from any assumed composition and density level of a planetary atmosphere which consists of CO_2 and N_2. The results are shown in Fig. 3. In the near future, the spectral radiation at temperatures of 10,000°K and higher will be investigated to explain the source of the excess radiation observed in Ref. 2.

TECHNIQUE AND FACILITY DEVELOPMENT

In order to measure the radiation from planetary gases in the vacuum ultra-violet region, a four-channel grazing spectrograph has been designed. This instrument will extend the measuring capabilities down to 500 Å in the ultraviolet where no measurements presently exist. In the 2000 to 5000 Å region a Jarrell-Ash spectrograph is being adapted to record 6 channels of spectral radiation data per shock tube run. Progress in the development of the device was reported in Ref. 3.

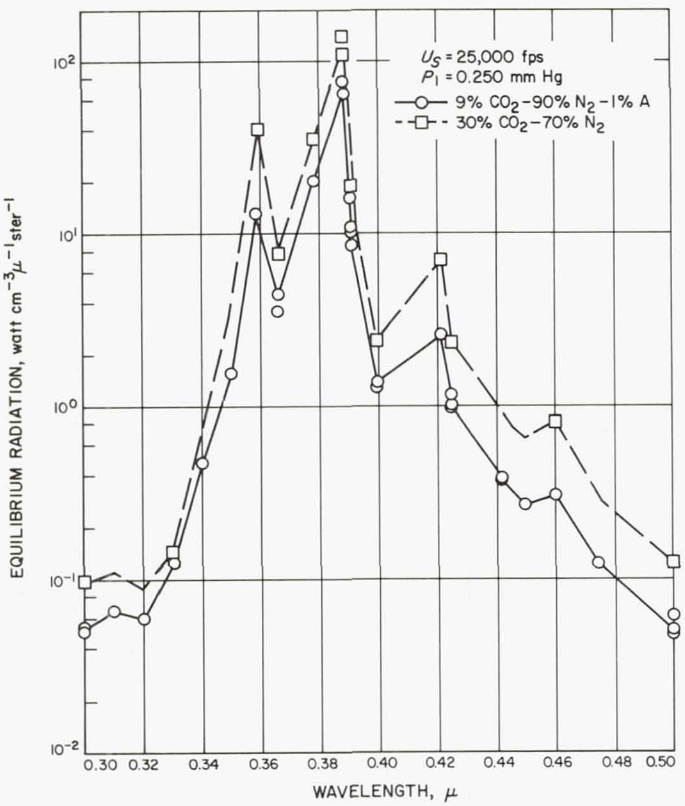


Fig. 1. Typical spectral radiation data

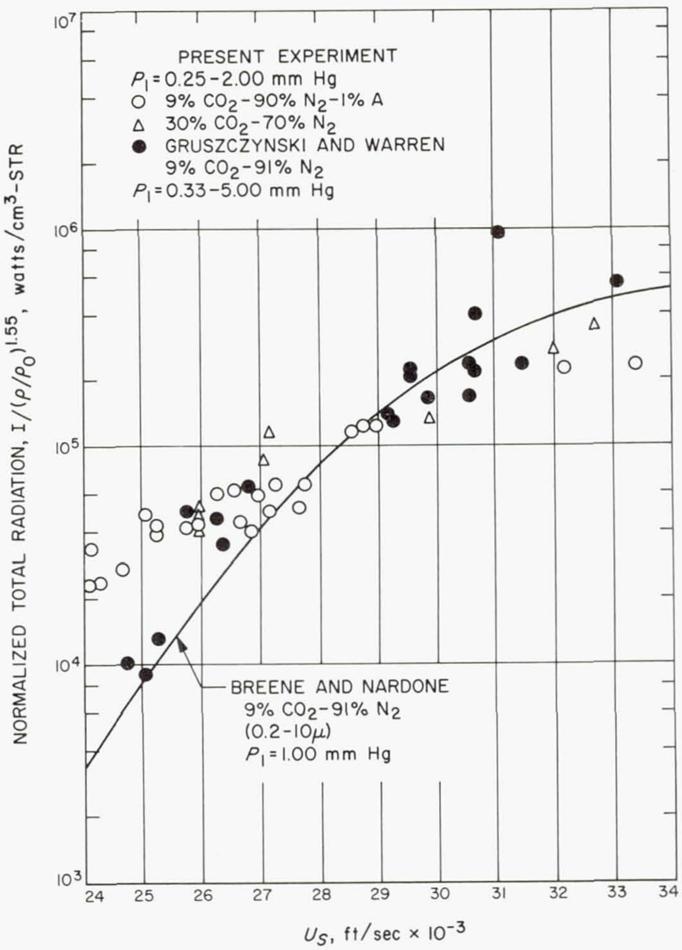


Fig. 2. Total radiation at low pressures

The 12-in. free-piston driven shock tube is being developed to provide a device for making studies in high enthalpy, low density, clean gases. The performance of the free-piston driver was reported in Ref. 4. It has not been fired as a shock tube yet, but will be in the near future.

A 43-in. Mach 12, shock tunnel nozzle has been designed and built for use with the 3-in. shock tube. Delivery of a few unavailable parts is expected shortly at which time initial calibration of the nozzle will be started. The tunnel has been briefly described in Ref. 5.

A study of the possibility of increasing the shock velocities attainable in the 6-in. arc heated shock tube has shown that by increasing the driver to driven area ratio to 1, shock speeds in excess of 52,000 ft/sec should be realized. The design of a 6-in. arc driver section is being completed. A double diaphragm section has been built for the 6-in. shock tube. This piece will permit the tube to be used as a cold driven facility in order to investigate the lower shock speed regions. Initially, it will be used to calibrate plasma probes.

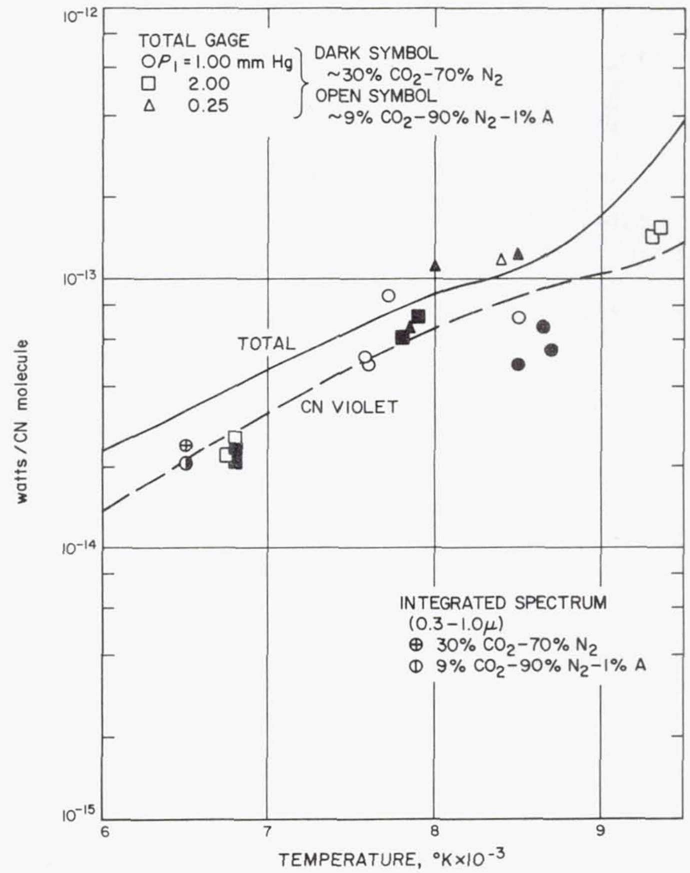


Fig. 3. Correlation of effects of composition on radiation from planetary atmospheres

CONTRACTS

A contract (JPL A5-327138) has been let with Northrop Space Laboratories to provide "Polaroid" data reading and reduction in support of the Hypervelocity Laboratory operation. The cost of the contract is $10,000 and will run for approximately one year. Since the contract has just begun, contractor performance data are not available.

MEETINGS

The following is a list of meetings attended in furtherance of the general task area:

1. AIAA, Second Aerospace Sciences Meeting.

2. APS, Second Shock Tube Symposium.

3. Supersonic Tunnel Association, Semi-Annual Meeting - Paper presented on the performance of the Hypervelocity Laboratory.

REFERENCES

1. Collins, D. J., and Menard, W. A., Measurement of the Thermal Conductivity of Noble Gases in the Temperature Range 1500 to 5000 Deg. Keluin, ASME Paper No. 65-HT-3, to be published.

2. Thomas, G. M., and Menard, W. A., "Experimental Measurements of Nonequilibrium and Equilibrium Radiation from Planetary Atmospheres", to be published in the AIAA Journal, 1965.

3. Menard, W. A., and Thomas, G. M., Progress with Spectrograph Calibration Experiments, JPL SPS 37-32, Vol. IV, page 104.

4. Babineaux, T. L., and Riale, B. R., Preliminary Performance of a Free-Piston Shock Tube Driver, JPL SPS 37-32, Vol. IV, page 101.

5. Livingston, F. R., Shock Tunnel Design and Performance, JPL SPS 37-29, Vol. IV, page 70.

OTHER REPORTS

The following report is related to previous work but was published since January 1, 1965.

1. Livingston, F. R., Experimentally Measured Effects of the Wall Boundary Layer on Shock Tube Performance, JPL TR 32-714, March 1, 1965.

20-INCH SUPERSONIC WIND TUNNEL
NASA Work Unit 124-07-04-01
JPL 324-701XX-7-3730

FACILITY OPERATION

The 20-in. supersonic wind tunnel is continuing to operate on a half-time basis by sharing the crews with the 21-in. hypersonic wind tunnel. The tunnel operates over a range of Mach numbers from 1.2 to 5.0 with high quality flow. Its variable density capability permits Reynolds number variations of a factor of 30. It is capable of performing tests in non-Earth atmospheres.

PLANETARY ENTRY STUDIES

Experimental efforts investigating the problems of Mars entry were continued. A brief study (Ref. 1) was made to investigate the effect of several base cavity shapes on the static stability of a rearward entering shape. No signigicant differences in static stability were observed, but the bow shock shape was observed to be unsteady in several cases. Further work is being planned for hypersonic Mach numbers. A continuing effort in support of Mars entry studies is planned.

The feasibility of using supersonic drogue devices to increase the total drag and stability of an entry capsule system is being investigated. The approach to the objectives has been primarily through experimentation in the JPL 20-in. supersonic wind tunnel, utilizing the JPL-developed free-flight technique. Such theory as is necessary is developed in order to derive meaningful results from the experimental program. A successful testing procedure (and hardware) has been devised, and is being refined. Early tests pointed out some of the parameters to be investigated (see Ref. 2 and 3). Figure 1 shows some results of a more recent test. One interesting qualitative result observed is the dynamic instability of certain body-drogue combinations (note that this observation was possible only through the restraint-free nature of the free-flight test technique).

A wind tunnel test is being prepared to collect more data on the drag parameters, and to begin carefully controlled efforts in the dynamic regime. This last is in conjunction with recent analytical work on the two-body dynamic system, utilizing an analog computer. An example of an analog computer solution to a simple analytic case is shown in Fig. 2.

Contact has been made with NASA Langley in order to establish a two-way information flow on decelerator device work. They are in favor of this and have forwarded information on their full-scale flight tests to foster consideration and/or planning of parallel wind tunnel (free-flight) tests at JPL.

Research into the nature of the dynamic stability of aerodynamic vehicles is continuing. The energy/integral data analysis method has been developed. This method is considered to be more versatile than all others presently in use. It is based on the total oscillatory energy defect observed during a cycle of oscillation. A preliminary presentation of the method was made recently to the Dynamic Stability Workshop at AEDC. Reference 4 contains a detailed description of the method.

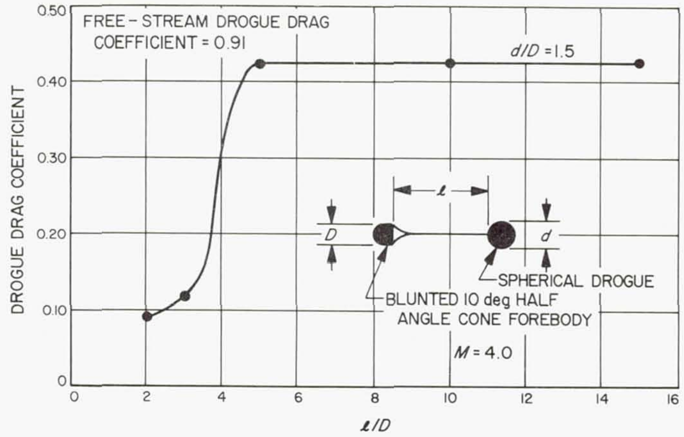


Fig. 1. Drogue drag coefficient vs trailing length

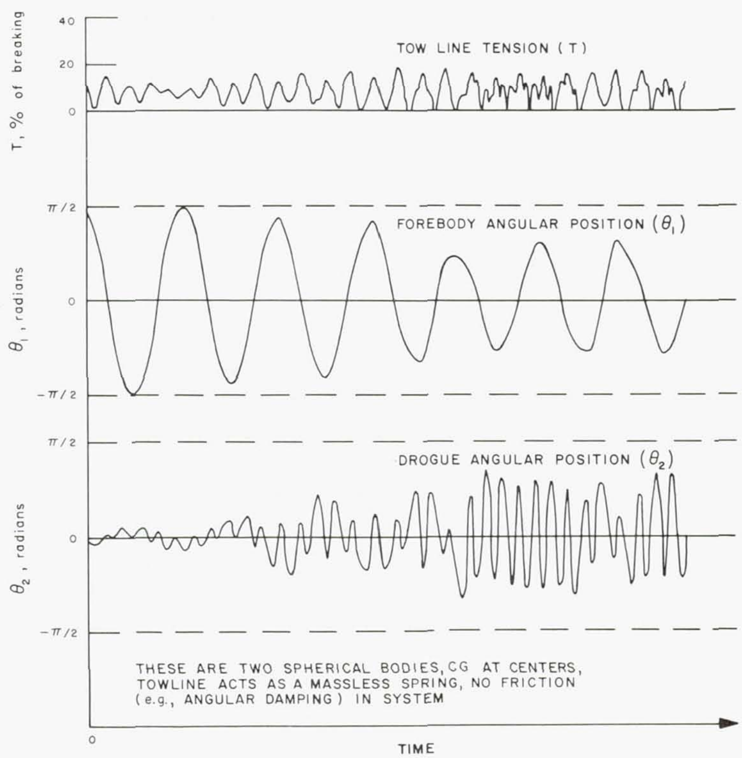


Fig. 2. Aerolog solution to simple two body problem

An experimental parametric study is being conducted using a basic 10-deg half-angle cone. The effect of parameters, such as flow conditions, nose bluntness, oscillation amplitude, center-of-gravity position, and roll rate on dynamic stability, are being investigated. A portion of the test data have been collected; the test program is continuing. Some sample results are shown in Fig. 3 and 4; more results are presented in Ref. 5.

Much of the dynamic stability test and data analysis work has been automated, thus permitting, for the first time, the acquisition and handling of large quantities of refined experimental data. This is expected to permit engineering personnel to spend more time analyzing results with less effort being required for acquiring and reducing data.

TESTING TECHNIQUES

Two testing techniques (free-flight with movie record and captive free-oscillation with Optron Tracker) have been developed to permit dynamic stability experimentation. Each of these two significantly different techniques produce high quality experimental results; they have been used to verify each other.

TESTING SUPPORT

Fluid physics research studies are being conducted at JPL. The 20-in. supersonic wind tunnel is supporting these studies by making the facilities available to the experimenters. A preliminary test in the 20-in. supersonic wind tunnel provided data which indicated that wall effects on a two-dimensional narrow wedge were sufficiently small to permit reliable base pressure measurements. Two succeeding tests using a wedge, with and without a splitter plate, have been conducted. Base pressures as well as pressures along the centerline of the splitter plate were measured. All data recorded appears to be highly reliable. Further testing will be conducted during FY 1966. The wake investigations will consist of flow field mapping near the separation edge and in the reattachment region as well as very detailed surface pressure measurements.

A second fluid physics research project is investigating transition in supersonic wakes. Four tests have been conducted in the 20-in. supersonic wind tunnel using a two-dimensional flat plate. An electronic variable frequency flow disturbance device was attached to the base of the plate. It was shown that the frequency of the disturbance influenced whether the disturbance decayed or developed into specific flow patterns (see Fig. 5). The results are being compared with linear stability theory. In addition, nonlinear stability behavior has been briefy studied. Further testing will be conducted during FY 1966. Investigations will be extended to cover shapes other than those of the flat plate.

Testing support also has been provided to NASA Edwards in the development of the Advanced X-15 as a ramjet test bed. Several test programs have been conducted to determine the static aerodynamic characteristics of the vehicle with various external stores, and with a much larger main engine. Support of other NASA centers and government agencies is being maintained when the facility is appropriate for the proposed tests.

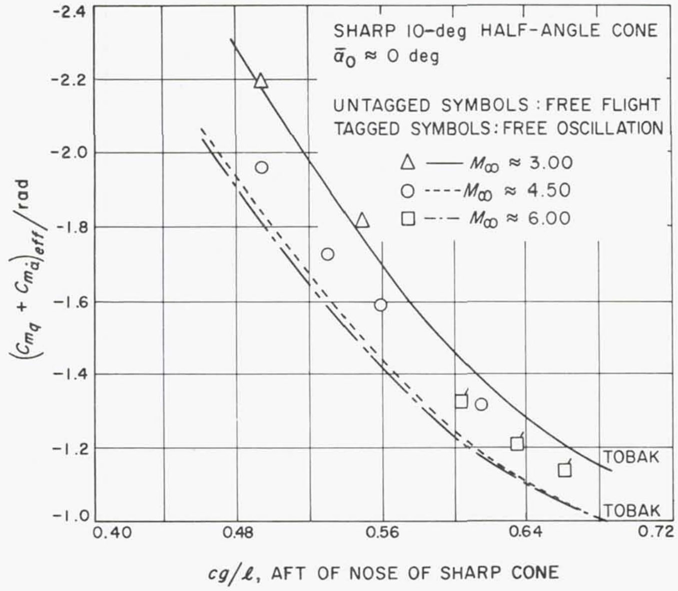


Fig. 3. Effect of center of rotation on dynamic stability for a sharp cone

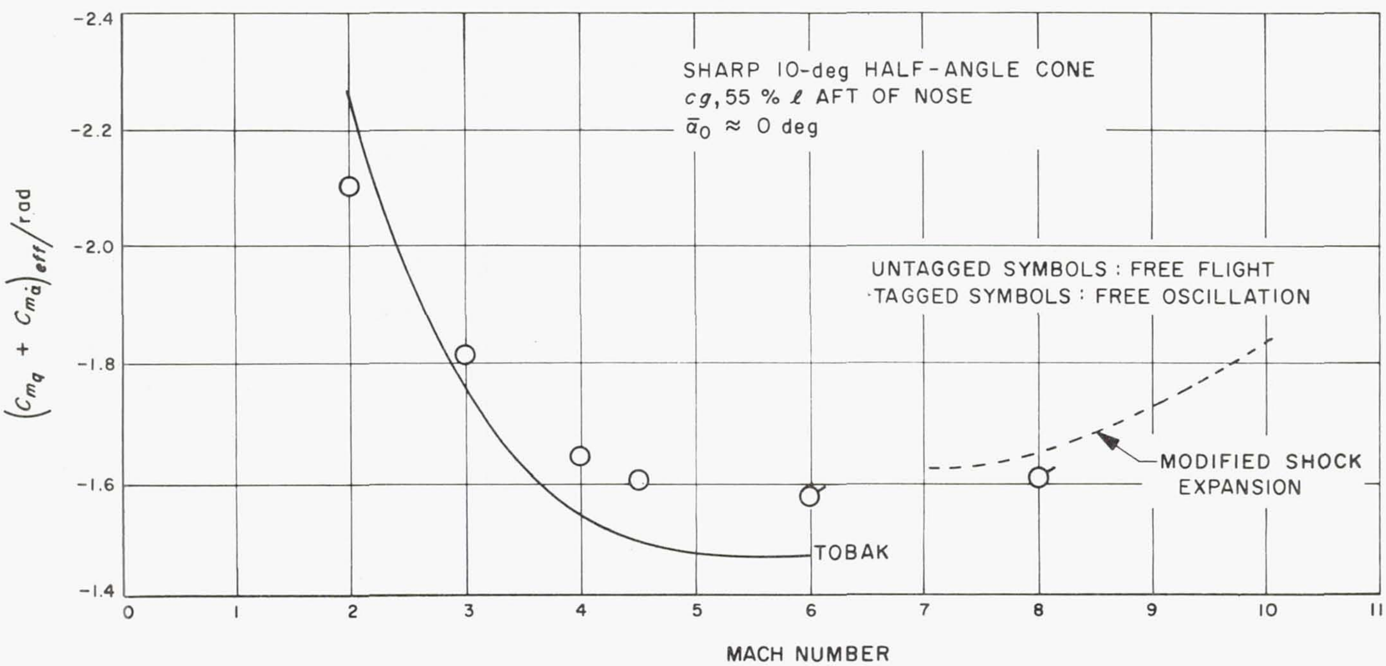


Fig. 4. Effect of Mach number on dynamic stability of a sharp cone

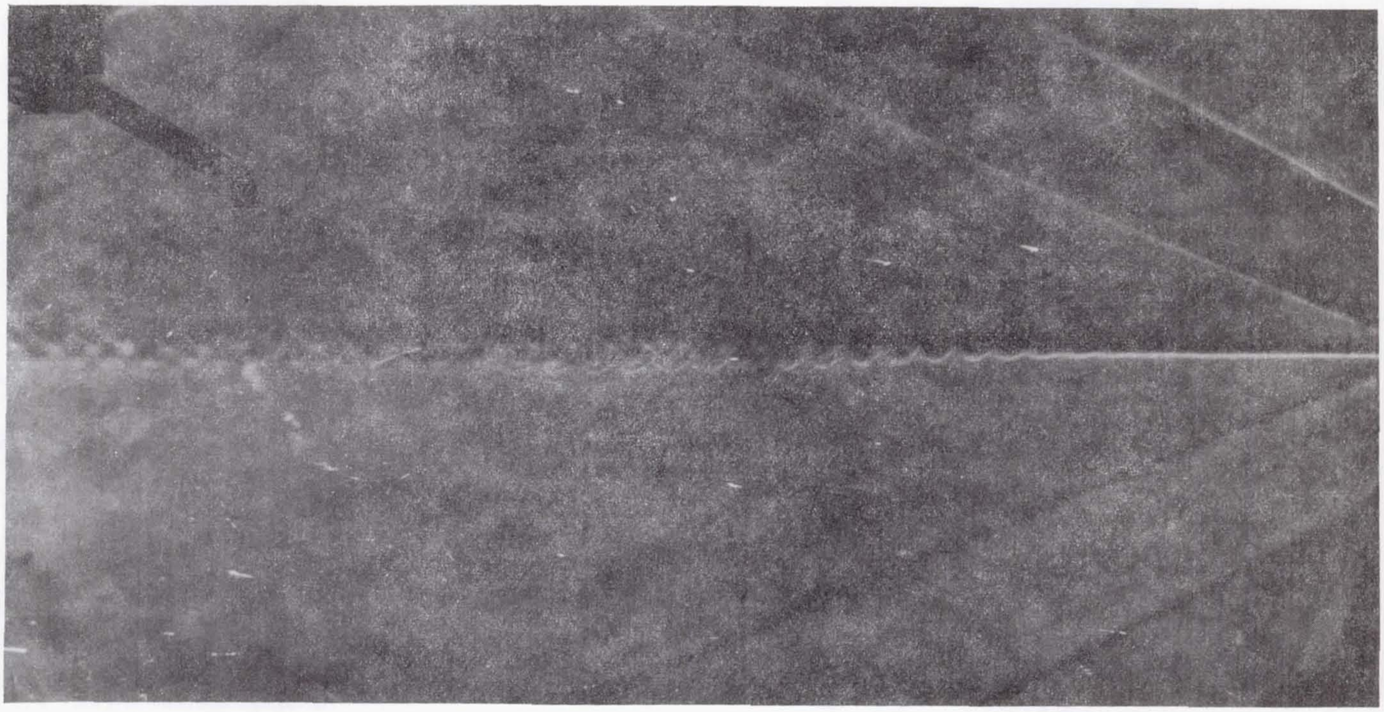


Fig. 5. Wake with tuned distrubance

MODIFICATIONS TO FACILITIES OR EQUIPMENT

The old hydraulic external balance has been removed from the tunnel. It had not been required for test use in 2 yr and maintenance of the device was an unnecessary burden. A new model support sector is being designed to provide greater strength, better angle-of-attack control and easier access for model instrumentation. The wind tunnel data acquisition and reduction system is being improved by increasing the memory capacity of the computer and by replacement of the site data presentation equipment with faster, more reliable printers.

CONTRACTS

A contract (JPL A4-229415) with Telecomputing Services, Inc. for the reading and reduction of free-flight movie film data has been renewed. The contractor's past performance has been very acceptable. The total funding committed to date is $45,000 and is shared with the 21-in. hypersonic wind tunnel.

MEETINGS

The following is a list of the meetings attended in furtherance of the general task area:

1. AIAA, 2nd Aerospace Meeting.

2. NASA, Research Advisory Committee on Aircraft Aerodynamics.

3. AAS/AIAA, Symposium on Unmanned Exploration of the Solar System.

4. AIAA/NASA, Flight Testing Conference.

5. AEDC, 2nd Dynamic Stability Workshop. Three papers were presented on Summary of JPL dynamic stability program.

6. NASA/AEDC, Strain Gage Balance Committee Meeting.

7. Supersonic Tunnel Association, Semi-Annual Meeting. Papers were presented on wind tunnel operations achievements.

REFERENCES

1. Weaver, R. W., "Free-Flight Capsule Afterbody Studies", SPS 37-32, Vol. IV, p. 95.

2. Goranson, G. M., "Mariner Forebody-Drogue Studies", SPS 37-24, Vol. IV, p. 70.

3. Goranson, G. M., "Free-Flight Body-Drogue Studies", SPS 37-26, Vol. IV, p. 78.

4. Jaffe, P., A Generalized Approach to Dynamic Stability Flight Analysis, TR 32-757 (to be published).

5. Jaffe, P., and Prislin, R. H., "Effect of Boundary Layer Transition on Dynamic Stability Over Large Amplitudes of Oscillation," AIAA Preprint No. 64-427, July 1964 (also, to be published in AIAA Journal of Spacecraft and Rockets, 1965).

OTHER REPORTS

The following reports relate to previous works that have been published since January 1, 1965.

1. Marte, J. E., and Weaver, R. W., "Langley 20-Foot Free-Spinning Wind Tunnel Dynamic Stability Test of Mars Entry Configurations", SPS 37-32, Vol. IV, p. 90.

2. Marte, J. E., Viscous Damping of Roll During Entry of a Mars Entry and Landing Capsule, TM 33-201, April 1, 1965.

21-INCH HYPERSONIC WIND TUNNEL
NASA Work Unit 124-07-04-02
JPL 324-704XX-7-3730

FACILITY OPERATION

The 21-in. hypersonic wind tunnel is continuing to operate on a half-time basis by sharing the crews with the 20-in. supersonic wind tunnel. The tunnel operates over a Mach number range of 4 to 11 with high quality flow. Its variable density capability permits Reynolds number variations of a factor of 30. It is capable of performing tests in non-Earth atmospheres.

PLANETARY ENTRY STUDIES

A test is being planned to investigate the effect of afterbody shape on the static stability characteristics of a proposed entry body shape. A continuing effort in support of Mars entry studies is being planned.

TESTING TECHNIQUES

As an extension of the previously developed wire launch free-flight testing, launch guns have been developed for use in both the supersonic and hypersonic wind tunnels. These devices effectively double the flight times observable through the tunnel windows. Descriptions of these devices are presented in Ref. 1 and 2.

A miniaturized FM pressure telemetering package small enough to be flown in a 1-in.-diameter cone has been successfully tested (Ref. 3). On the average, six flights can be made before the package is destroyed. Very accurate base pressure measurements have been made at M = 6 and 8 for 10- and 15-deg half-angle cones. A typical time dependent pressure trace is shown in Fig. 1. A modification of the basic telemeter package to permit it to be used to make temperature measurements is being bench tested.

TESTING SUPPORT

A brief experimental study, in support of the Surveyor project was conducted in the near vacuum of the JPL 25-ft space simulator. The flow field in the vicinity of three parallel hypersonic jets which formed an equilateral triangle impinging on a surface was mapped by photographing tuft patterns. Special effort was taken to determine the flow characteristics in the region of the centroid of the three-jet system and how they changed as the jets approached the impingement plane. The results of the study are presented in Ref. 4 and a movie supplement.

Testing support has been provided to NASA Edwards in the development of the Advanced X-15 as a ramjet test bed. Several test programs have been conducted to determine the static aerodynamic characteristics of the vehicle with various external stores and with a much larger main engine.

Support has also been provided NASA, MSFC in the experimental investigation of the boundary layer separation phenomenon being observed on both the Saturn IB and 5. Several cold-wall model tests have been conducted and more are being planned.

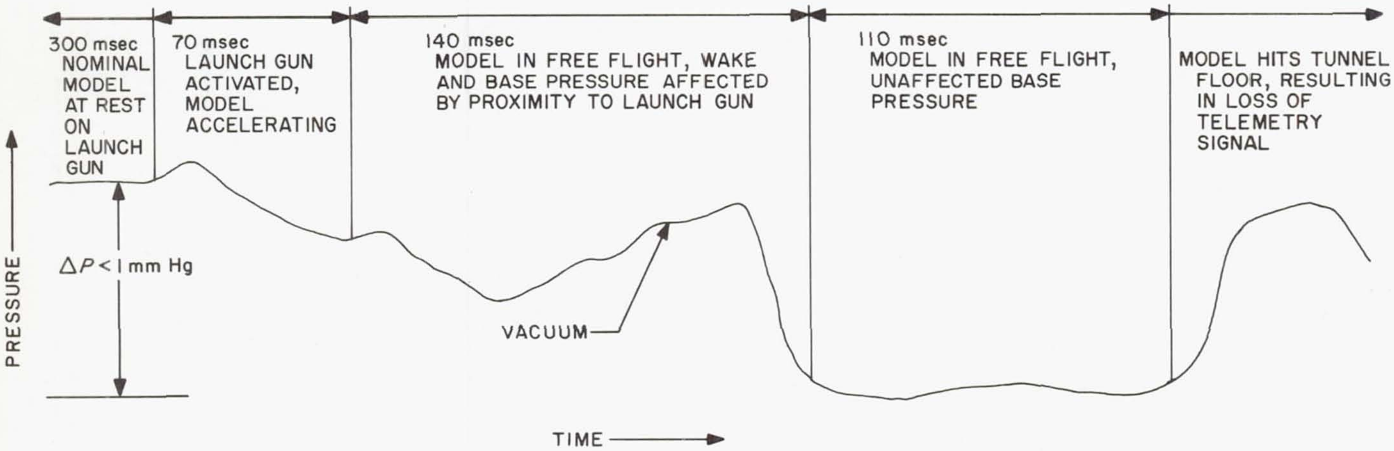


Fig. 1. Typical time dependent trace

Support of other NASA centers and government agencies is being maintained when the facility is appropriate for the proposed tests.

MODIFICATIONS TO FACILITIES OR EQUIPMENT

The wind tunnel data acquisition and reduction system is being improved by increasing the computer memory capacity and by replacing the site data presentation equipment with faster more reliable printers.

An auxiliary tunnel air circuit has been designed and built which bypasses the hypersonic tunnel. This circuit, presently called "Leg 2", was built to perform rocket nozzle tests. Its use will be extended at a later date.

CONTRACTS

A contract with Telecomputing Services, Inc. for the reading and reduction of free flight movie film data has been renewed. The contractor's past performance has been very acceptable. The total funding committed to date is $45,000 and is shared with the 20-in. supersonic wind tunnel.

MEETINGS

The following is a list of meetings attended in furtherance of the general task area:

1. AIAA, 2nd Aerospace Meeting.
2. NASA Research Advisory Committee on Aircraft Aerodynamics.
3. AAS/AIAA, Symposium on Unmanned Exploration of the Solar System.
4. AIAA/NASA, Flight Testing Conference.

5. AEDC, 2nd Dynamic Stability Workshop - Three papers were presented on the JPL dynamic stability program.

6. NASA/AEDC, Strain Gage Balance Committee Meeting.

7. Supersonic Tunnel Association, Semi-Annual Meeting - Papers presented on wind tunnel operation achievements.

REFERENCES

1. Holway, H. P., Herrera, J. G., and Dayman, B., Jr., A Pneumatic Launcher for Free-Flight Testing in a Conventional Wind Tunnel, TM 33-177, July 30, 1964.

2. Holway, H. P., Pneumatic Model Launcher for Free-Flight Telemetered Base Pressure Models, SPS 37-31, Vol. IV, p. 135.

3. Welton, J. T., and Harrison, R. G., Jr., Free-Flight Telemetry, SPS 37-32, Vol. IV, p. 89.

4. Marte, J. E., and Fox, N. L., An Experimental Study of the Flow Field Produced by Three Hypersonic Jets Impinging on a Surface in a Vacuum Environment, TM 33-231 (to be published).

OTHER REPORTS

The following reports relate to previous work that have been published since January 1, 1965.

1. Wood, R. D., and Hemstead, R. J., "Optimum Supersonic Ejector Performance Characteristics", SPS 37-32, Vol. IV, p. 97.

2. Laumann, E. A., Comparison of Experimental and Theoretical Aerodynamic Heating Results in Air-Carbon Dioxide Mixtures, TR 32-715, January 15, 1965.

3. Lund, D. E., and Laumann, E. A., Heat Transfer Test of the Mariner IV Shroud Separation Assembly in the JPL 21-Inch Hypersonic Wind Tunnel, WT 21-185 (to be published).

Page Intentionally Left Blank

SPACECRAFT STRUCTURES (124-08)

SPACECRAFT SHELL STRUCTURES
NASA Work Unit 124-08-01-01
JPL 324-80101-2-3530

STRUCTURAL ANALYSIS SYSTEM (SAS) COMPUTER PROGRAM

The SAS Computer Program is based on the analysis techniques of the direct stiffness method. Fundamental to this method is the problem of force averaging to predict element stresses. This problem was encountered in the elements of the SAS and considerable work has gone into its solution. The current approach, which is in final checkout, is expected to yield accurate stress values.

Modules of the SAS Program that have been completed and that represent an integrated analysis tool have been given to Langley Research Center and Manned Spacecraft Center at their request. Both Langley and MSC have successfully completed runs on their computers. One outgrowth of JPL activity in this area is the greater impetus to complete program documentation.

Modifications, as listed in the last progress report, are in process by contract extension with Philco Corporation. This work is approximately 75% complete, with no known problems anticipated in completing the work. Participation by JPL personnel in checkout of these modifications has been extensive as it has been in checkout of other modules of the SAS Program.

A paper published in SPS 37-32, Vol. IV (February 1, 1965 to March 31, 1965) entitled "Structural Analysis System Program Evaluation of Triangular Plate Stiffness Element" included a description of the plate problem formulated to check out the stress calculations on the SAS and a summary of modal and frequency data of a dynamics calculation.

A report describing the functions and capabilities of the SAS Program was completed and is in process of publication as a JPL Technical Memorandum (TM 33-220). A similar report summarizing the test problems run in checkout of the SAS program is in preparation.

Professor H. Martin of the University of Washington has been retained as a consultant on a one-day-per-week basis and is continuing to study the sandwich shell element problem. Based upon a meeting with him on March 25 and 26, indications are that he will be able to derive an accurate element representation for sandwich structure.

In October of this year, cognizant JPL personnel of the SAS Computer Program will attend the Second Annual Conference on Matrix Structural Analysis to be held at Wright Air Development Center in Dayton, Ohio. At this meeting, a paper will be presented that summarizes work now being carried out to evaluate the optimum mass distribution that should be used in calculations of plate and shall mode shapes and natural frequencies.

THERMAL STRESSES IN SHELL STRUCTURES

A JPL Technical Report, in process of publication, describes the results of a theoretical study of thermally loaded shells. The report will be released in the first quarter of FY 1966. It is expected this work will be continued to evaluate the stress tolerance due to variations in temperature prediction for a typical shell structure (sandwich) likely to be used in capsule design. A second report, also in process of publication, contains analytic results of a study to assess the influence of shear stresses on the deflection of a spherical shell loaded by a central point load. The local variation of stress near the applied load was of prime concern.

ENTRY DYNAMICS
NASA Work Unit 124-08-05-01
JPL 324-80501-2-3530

A JPL competitive procurement is in process for an estimated cost of $32,000. The objective is to identify potential aerothermoelastic problems, analyze the factors involved, and recommend methods of solving or circumventing the problems identified.

Structural dynamics personnel at NASA Ames Research Center made valuable suggestions that helped formulate the statement of work at discussions held there in April 1965.

Page Intentionally Left Blank

SPACE VEHICLE ENVIRONMENTAL FACTORS (124-09)

HIGH VACUUM RESEARCH MOLSINK
NASA Work Unit 124-09-04-01
JPL 324-90301-2-3750

SPACE MOLECULAR SINK SYSTEM

Figure 1 is a perspective view of the 10-ft space molecular sink simulator (MOLSINK) which has been completely designed and is now under construction. This facility research tool will be used to determine the design philosophy necessary to obtain the optimum combination of MOLSINK performance and cost. The building has been renovated, the chamber support foundation poured and the hydraulic lift installed. Requests for quotations have been submitted to prospective vendors for the fabrication of the vacuum chamber and the molecular trap array. The basic system is scheduled to be completed during the third quarter of FY 1966, at which time experimental evaluation of various combinations of pumping, trapping and operating techniques will be undertaken.

LABORATORY EXPERIMENTS

The molecular trap theory has been experimentally verified using cryogenic quartz crystal microbalances (CQCM), a molecular flux detector, in the small 18-in. MOLSINK system, Fig. 2. The results of this experiment as well as the function and construction of the CQCM have been reported in Space Program Summary 37-30, Volume IV, and at the 1965 NASA Lewis High-Vacuum meeting.

This molecular flux detector is currently being used to measure the back-streaming of a turbomolecular impact pump and an LN_2 trapped oil-diffusion pump for evaluation of their utility in the MOLSINK system. The effectiveness of the 18-in. MOLSINK system in providing a molecular sink environment is being investigated by accelerated testing of several Mariner camera shutter solenoids and a shutter subsystem. These experiments will be reported in future numbers of the Space Programs Summary, Volume IV.

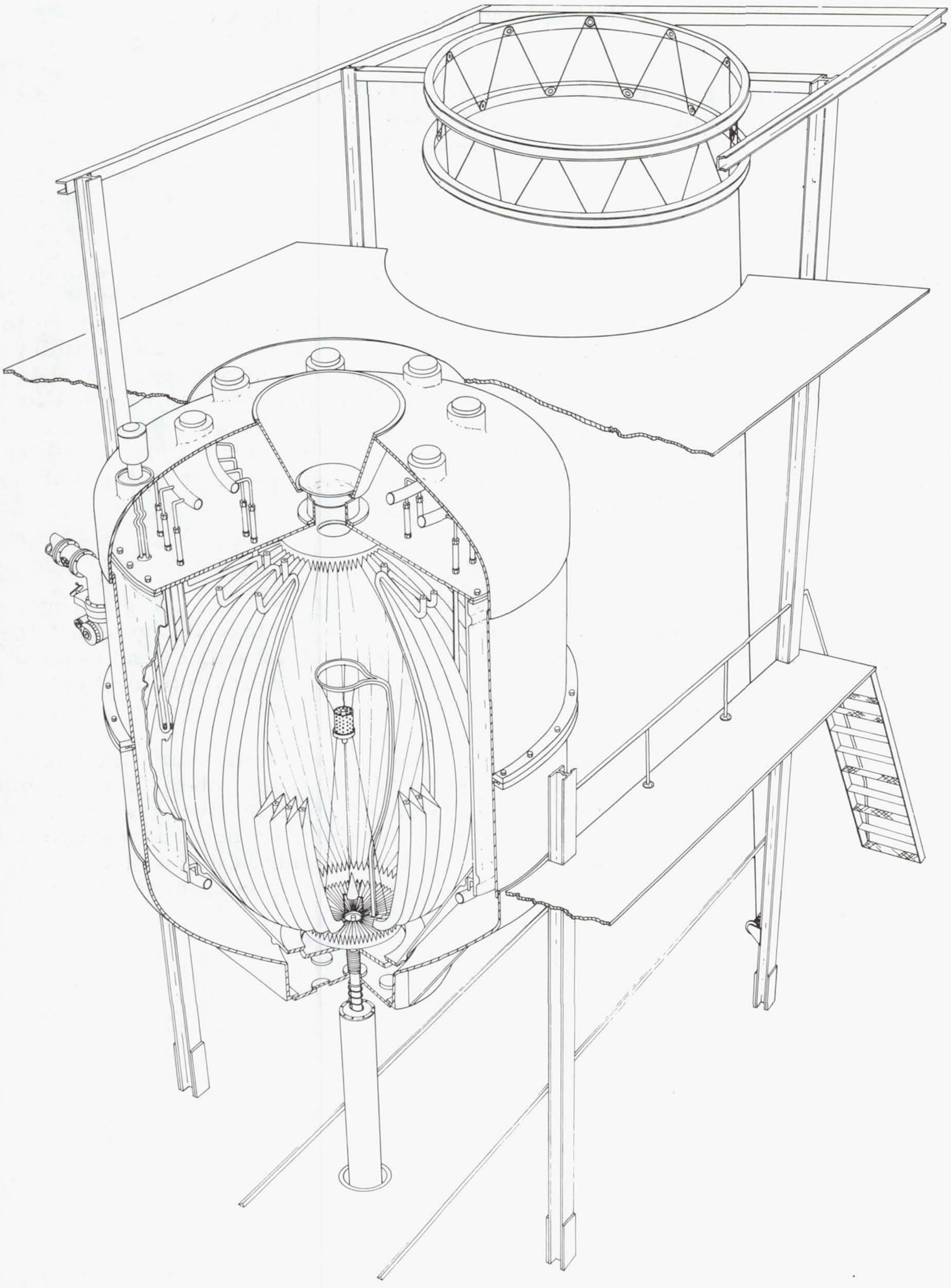


Fig. 1. Space molecular sink simulator

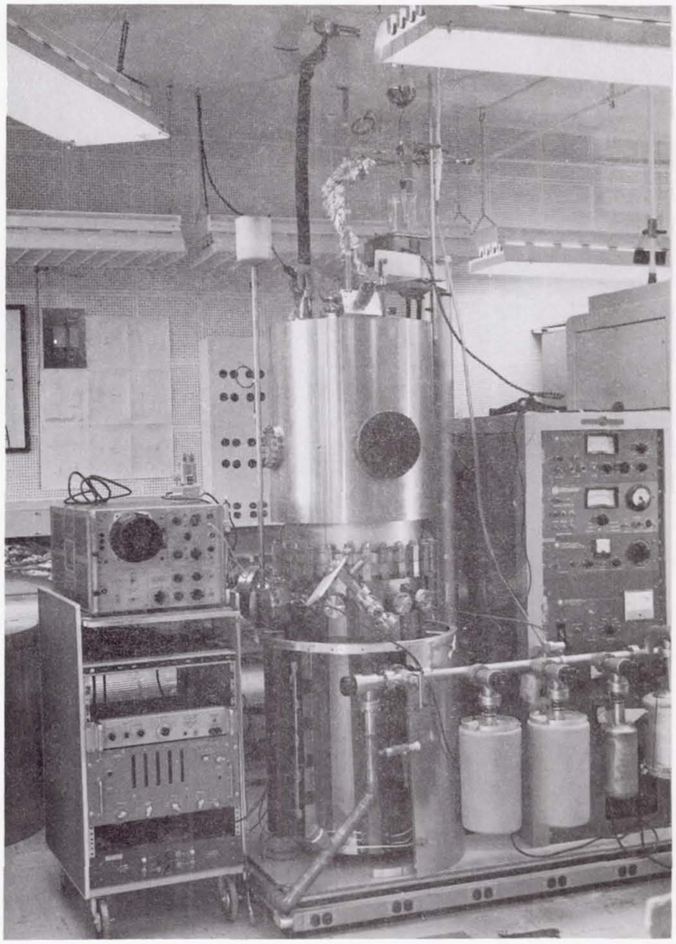


Fig. 2. 18-in. MOLSINK chamber

Page Intentionally Left Blank

EFFECT OF ENVIRONMENT ON SPACECRAFT TEMPERATURE CONTROL MATERIALS
NASA Work Unit 124-09-05-01
JPL 324-90401-2-3510

ACTIVITIES DURING THE REPORT PERIOD

Effort during the second half of FY 1965 has been primarily completion of a FY 1964 AD funded contract (JPL 950746) (NASA Task 33-74-740-100-09-05). This work has included a long term test (8,000 Sun-hr test on selected coatings), analysis of data, analysis of a very extensive literature search on the photolysis of zinc oxide, and preparation of a final report. As a result of finding a new, commercially available silicone with equivalent stability, the silicone synthesis work was discontinued.

Earlier tests had shown the inorganic system to be somewhat more stable than the organic for a 4,000 Sun-hr test. The results of the long test completed during this period showed a reversal of the relative stability for 8000 equivalent Sun-hr, indicating a moderate increase in degradation rate with test duration for the inorganic systems but a constant or decreasing rate for the organics.

The above results and others are presented and discussed in detail in the final report.

The existing IITRI contract has been supplemented and extended to continue the work on zinc oxide photolysis during the remainder of calendar year 1965. This supplement is funded with FY 1965 funds. Effort in the photolysis area during the second half of FY 1965 has been limited to a detailed review of the spectral characteristics of previous test results and review and analysis of the Lockheed program (funded by the Marshall Center) on photolysis. It is the intent to supplement rather than duplicate the Lockheed work during this program. To this end discussions have been held with the cognizant Marshall people.

Due to manpower limitations at IITRI and the desirability of a slow systematic approach, this program has been decelerated and the effort will continue until approximately the end of the calendar year 1965.

A joint meeting was held at IITRI in January 1965, to coordinate the activities at IITRI funded by Ames, Marshall, and JPL. Attendees included Mr. E. Streed of Ames, Mr. D. W. Gates of the Marshall Center, and Dr. J. Lucas of JPL.

Due to delay in program definition and start of experimental work on the Headquarters funded contract at Avco-Tulsa, and subsequent manpower limitations at JPL, no effort has been initiated in work with radiation other than 2000-4000 Å ultraviolet. However, we have participated with Ames in outlining plans and objectives of the Avco-Tulsa contract, including a meeting at Tulsa, Oklahoma, May 19, 1965. ASD is sponsoring similar work at Avco and the representative, H. H. Hormann, also participated in the meeting.

Data from the absorptivity standard on the Mariner-Mars vehicle indicates a significant need for high energy particle radiation and combined environment tests.

An informal meeting of government and industrial investigators, devoted to discussion of high energy electromagnetic and particle radiation, was organized in March and was attended by 26 people representing 18 organizations. The attendance and participation indicates a high level of interest in environmental effects in this area. There is a great need to coordinate activities of various investigators in this area, to avoid excess duplication, and to attempt to avoid inadequate or inaccurate evaluations.

TEMPERATURE CONTROL OF LARGE SPACECRAFT
NASA Work Unit 124-09-05-02
JPL 324-90501-2-3530

THERMAL SCALE MODELING

Thermal scale modeling in steady state conditions, at 0.43 scale, of the Mariner Mars 1964 Spacecraft, which is being carried out on contract by Arthur D. Little, Inc. (ADL) has proceeded on schedule. This contract was initiated in FY 1964 with NASA/JPL Contract 950789 under NASA Work Unit 124-09-05-02 and JPL 324-00905-2-3540. The total funds for the entire contract remained at $189,708 as during the previous report period. The major effort by the contractor during the report period was the construction of hardware, the preparation for test, arrangements for test in a NASA Lewis Research Center solar simulator, and the completion of tests called for in Phase III. In this phase a scale model of all significant external appendages in addition to the basic octagon of the Mariner spacecraft was tested in a cold wall, vacuum chamber with solar simulation over the octagon. It should be noted that at the beginning of Phase III it was decided to model the flight spacecraft, Mariner IV, rather than the Mariner Mars 1964 temperature control model (TCM) and compare with flight temperatures; this was done because there existed a substantial uncertainty in the intensity of the simulated solar beam in previous TCM tests, the results from which were to have been used for comparison with Phase III model tests. Appendages modeled included upper and lower flight thermal shields, solar panel stubs, magnetometer, ion chamber, Sun sensors, trapped radiation detector, canopus tracker, TV scan platform, and omni and high-gain antennas. Photographs of the prototype and the model are shown in Fig. 1 and 2 respectively.

The Phase III model tests were carried out in the 6-ft solar simulator chamber at Lewis Research Center the week of June 7th. Dr. J. W. Lucas and Dr. J. M. F. Vickers, the cognizant engineer, attended the tests. Four tests were carried out, all under solar simulation. The first two tests were for conditions during cruise between Earth and Mars and had the same internal power dissipation. Test I for Earth cruise was at approximately 0.7 Earth solar constant while Test II for Mars cruise was at approximately 0.5 Earth solar constant. The last two tests were for conditions after planet encounter and during the planned playback to Earth of the TV pictures of Mars. Internal heat dissipation is different from the previous flight modes and the intensity was approximately 0.4 Earth solar constant. Test III, as for Tests I and II, was with electrical heating to the solar panel stubs to operate them at flight temperatures predicted on the basis of solar panel solar absorptance and infrared emittance provided to the contractor. Test IV was with increased heat to the panel stubs to determine the sensitivity of the remainder of the spacecraft to variation in solar panel temperature.

Preliminary raw data comparison with prototype temperatures (Mariner IV) in flight for Tests I and II, and with flight predictions for Test III, were very good. In Test I 75% of the temperatures agreed within 5°F; in Test II 65% of the temperatures agreed within 10°F; and in Test III 70% agreed within 15°F. The temperatures in Test IV agreed somewhat better than in Test III.

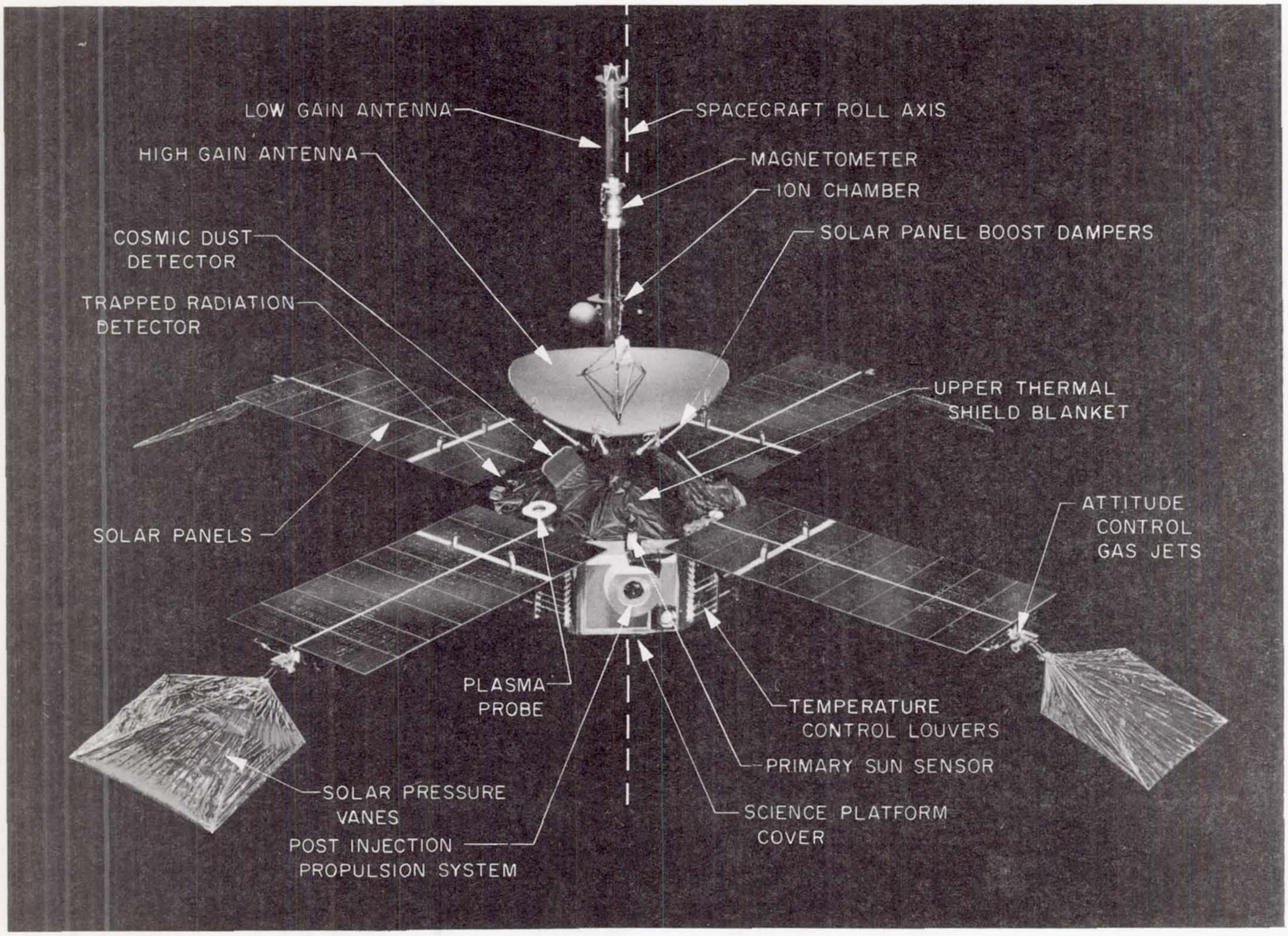


Fig. 1. Mariner Mars 1964 spacecraft

The Phase II Technical Report was delivered to JPL by ADL in January; the report was distributed to NASA Headquarters and NASA Centers, and to industrial firms and universities known to be interested in thermal modeling. The ADL project engineer, F. Gabron, and his deputy, R. Johnson, visited JPL in late January to report orally on Phase II and to obtain technical information on the Mariner Spacecraft for Phase III. A paper based on Phase II and titled Thermal Scale Modeling of a Modified Prototype of the Mariner Mars 64 Spacecraft by F. Gabron, R. W. Johnson, and J. M. F. Vickers was prepared in this period and accepted for presentation on July 27th at the AIAA Second Annual Meeting and Technical Demonstration in San Francisco. ADL was allowed a no-cost delay of 3 wk in the date for going into test on Phase III because of the change from modeling the Mariner TCM to Mariner IV. For this reason the report on Phase III is to be submitted during the first month of FY 1966. F. Gabron is to give an oral presentation at JPL on Phase III at that time.

Dr. Vickers prepared a summary of the modeling work as of the end of January. It is titled "Thermal Scale Modeling" and appeared in JPL SPS No. 37-31,

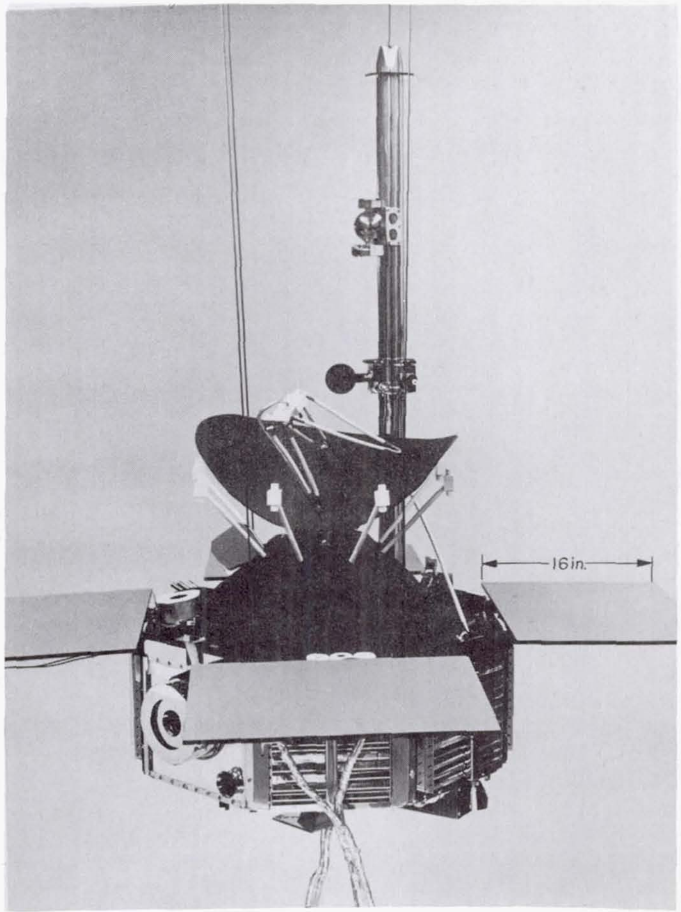


Fig. 2. Half-scale model of Mariner Mars 1964

Vol. IV, pp. 111-112, February 28, 1965. He also authored the paper "Thermal Scale Modeling" in Astronautics and Aeronautics, Vol. III, No. 5, pp. 32-39, May 1965.

A Statement of Work for an additional Phase IV of the present contract to ADL was prepared. The purpose of this phase will be to prepare an instruction manual for use by project offices and project temperature control engineers on the application of thermal scale modeling to spacecraft such as the Mariner Mars 1964 but including an entry capsule for subsequent planet atmosphere entry. Phase IV was funded from FY 1965 in the amount of $15,000 and it is to be awarded early in FY 1966.

Preliminary plans are being made to test the scale model from Phase III in a JPL solar simulator. It is planned that a NASA Headquarters research grant on transient thermal scale modeling will be technically monitored. Also, further effort to resolve temperature discrepancies in Phase III and determine design means for minimizing them in similar portions of subsequent spacecraft is planned. $40,000 in out-of-house funds has been budgeted in FY 1966 for this purpose.

ACTIVE TEMPERATURE CONTROL DEVICES

No work was performed on active temperature control devices during the report period because T. O. Thostesen, the engineer in charge of the work, was reassigned to project spacecraft work and his replacement will not join JPL until July 1965.

It is planned that effort on such devices will be resumed early in FY 1966.

CONDUCTION AND RADIATION IN SPACECRAFT TEMPERATURE CONTROL
NASA Work Unit 124-09-05-03
JPL 324-90601-2-3530

COMPUTER PROGRAMS

The Nodal Program and the Arthur D. Little Method of Zones Program were compared for a common radiation-conduction coupled-heat transfer problem. The steady-state case for both programs agrees exactly. For the transient case there is a slight but negligible difference between the two results.

CONFAC I and CONFAC II are operative on the JPL 7090-7040 direct-couple computer system.

During FY 1966 a general radiation-conduction coupled computer program will be formulated. Both direct analytic methods and Monte Carlo methods will be considered for use.

REAL SURFACE EFFECTS

Analytical heat-transfer studies to isolate, assess the magnitude of, and determine means for eliminating the substantial discrepancies which often occur between test results and analytical prediction were continued. These studies are of real-surface radiation effects which are ignored in engineering calculations at present but are regarded as a primary source of errors.

1. A detailed radiation-conduction coupled analysis, based upon the diffuse idealization was previously completed for a simplified version of the Ranger TV tower. This analysis is currently being programmed for numerical solution on an IBM 7094 computer. To date, separate programming of the conduction equations and radiation equations has been completed. Coupling of these two separate aspects remains to be accomplished. Numerical solutions for radiative heat transfer only has been completed and is reported in JPL SPS 37-32, Vol. IV, pp. 75-79. Analytical work involving specular surfaces has resulted in the formulation of a completely general analytical technique for obtaining view functions and view factors to images formed in non-planar, specular surfaces. Sample problems have been solved to demonstrate the technique. Preliminary results in this area are reported in JPL SPS 37-31, Vol. IV, pp. 112-115. A report thoroughly covering the work is currently being prepared.

2. Experimental work for verification of analytical work in real surface radiation heat transfer is currently being planned. Proposals have been solicited and received for the fabrication of a small (12-in. -diameter beam) solar simulator.

3. A great deal of effort was directed towards the development of a total spectrum, absolute radiometer. This radiometer employs a thermally guarded conical-cavity radiation-sensor. The sensor is maintained at constant temperature by supplying electrical power to the detector. The amount of power supplied is an absolute indication of the amount of unknown radiation incident on the detector. Fabrication of a prototype radiometer has been completed and experimentation is currently in progress. Small difficulties involving detector accuracy have been encountered which will require some modifications to the prototype. Systematic errors from 1-20% are currently being encountered. Figure 1 is a diagram showing the control circuits for the detector.

4. Work on polarization effects and nongray effects has not progressed because of the need for greater effort on the radiometer than expected. The following proposals were evaluated at NASA Headquarters request:

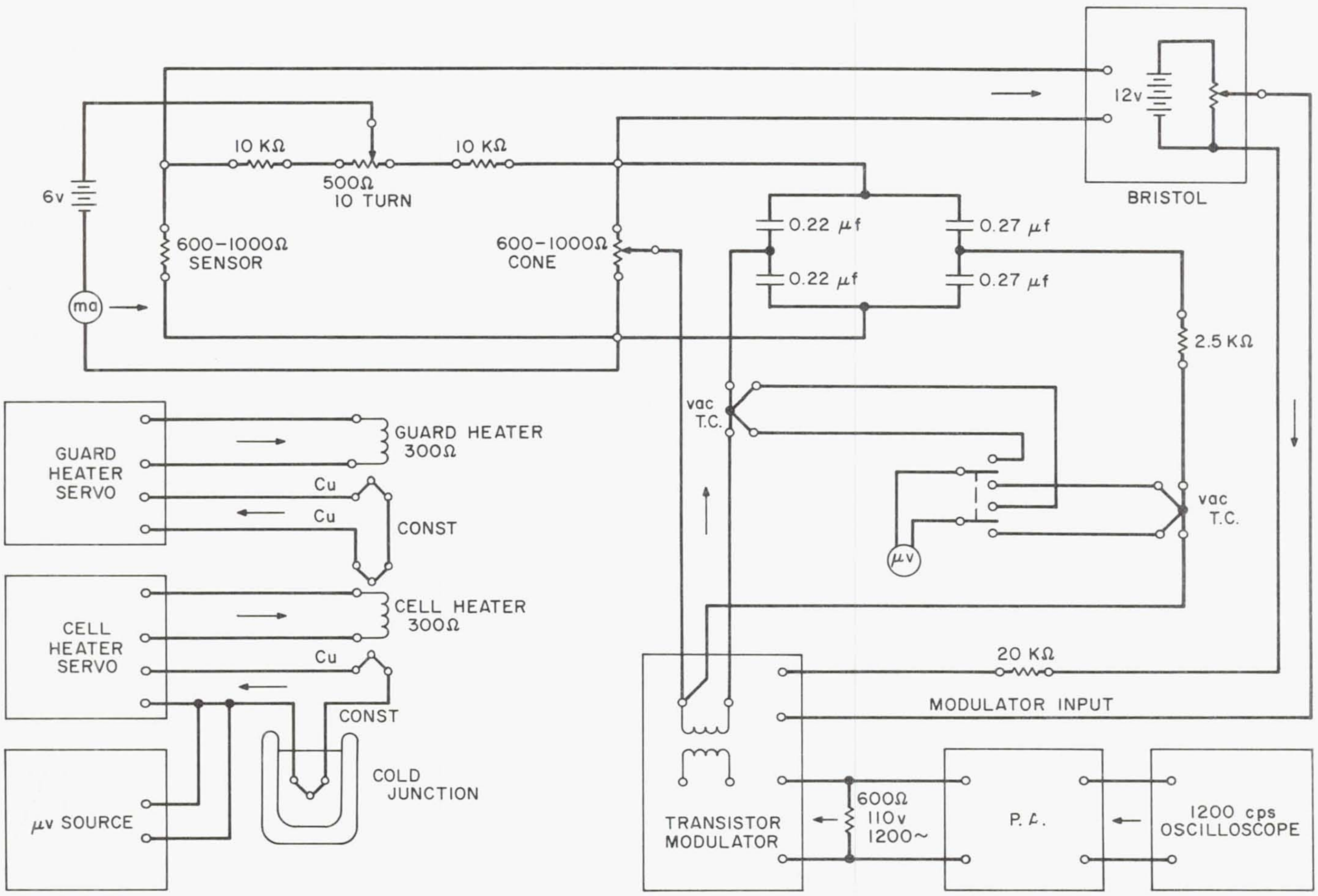


Fig. 1. Cavity detector diagram

a. Investigation of Radiation Surface Properties Under Non-Equilibrium Conditions, from Professor R. Viskanta of Purdue University, SC No. 15-005-(024).

b. The Thermal Radiation Characteristics of Specular-Diffuse Grooves with Tilted Walls in the Solar-Space Environment, from Dr. J. Parmer of West Virginia University, SC No. 49-001-(009).

During the Next Period the Following Activities are Planned:

1. Programming of radiation-coupled analysis will be completed for the simplified Ranger TV tower. An experimental effort to investigate the adequacy of the analysis will be initiated. This experimental effort will begin upon delivery of the small solar simulator light source which is expected to be at the middle of the period. The experimental work will include careful calibration of all elements composing the experimental facility.

2. Effort will be directed towards eliminating current systematic errors in the present radiometer prototype. Upon completion of the prototype, a contract will be let for the fabrication of several radiometer units including electronic control equipment. Contracting for the latter is expected to occur towards the end of the next period.

3. Reformulation of the equations for studying nongray radiant heat transfer phenomena will be completed in order to eliminate numerical difficulties encountered in the previous analysis. Also the study of directional and polarization effects in a simple 90-deg wedge is to be completed.

THERMAL JOINT CONDUCTANCE

The joint conductance apparatus was leak checked; the best vacuum was 10^{-7} torr. It was then learned that it would be necessary to move the apparatus, together with the remainder of the Thermodynamics Laboratory, back to the central JPL location. The move took place in May and caused considerable delay in the buildup of the apparatus. It is now expected that the apparatus will be in operation early in FY 1966. The first tests in the apparatus will be as follows: (1) calibrate by measuring the conductivity of ARMCO iron, (2) check out by measuring the joint conductance across cut bars, (3) measure joint conductance of simulated bolted joints.

Theoretical work on joint conductance has been continuing. The conductance across joints in which each of the two mating surfaces is assumed to be at a uniform temperature was computed by Professor Arthur M. Clausing as a portion of effort on NASA Research Grant NsG 242, Supplement No. 2, and was reported in his report ME-TN-242-2 dated April 1965. In-house analysis, in co-operation with Professor B. T. Chao, of joints in which the heat flux across the mating surface is assumed to be uniform, and joints consisting of thin-shell plates, was initiated. Also, formulation was begun of the necessary computer programs to allow for a variable joint conductance and to aid in analysis of the experimental data to be taken. These analyses will be continued in FY 1966.

Experimental investigations of thermal conductance in a bolted joint specifically designed for low thermal conductance and high structural rigidity were carried-out. The jointed member, including the bolt, were thermally isolated using commercial ball bearings with the balls acting as constrictive resistances to the flow of heat. Structure rigidity is inherent due to solid metal-to-metal contact of the angular contact bearings. Results indicate a thermal conductance for the joint of less than 0.02-w/°F. A report describing the experiments and presenting detailed results will be prepared early in FY 1966.

Two NASA Headquarters research grants were technically monitored. As a portion of this effort Dr. John Hultberg visited Professor Arthur M. Clausing at the University of Illinois and Dr. John W. Lucas visited Professor Henri Fenech at Massachusetts Institute of Technology. Monitoring of both contracts is anticipated during the next report period.

Two proposals in the joint conductance area were reviewed at NASA Headquarters request:

1. Experimental Investigation of Heat Transport Across Bolted Joints in Vacuum Surroundings, from A. D. Little, Inc., SC No. 22-041-(017).

2. Proposal to Develop a Technique for Predicting the Thermal Resistance at Fastened Joints, from General Electric Co., SC No. 39-0380(083).

SOLAR SIMULATION EFFECTS

A statement of work on thermal effects of typical examples of noncollimated solar simulation beams impinging on representative models was completed; the Facilities Division assisted with technical recommendations. An RFP was prepared for distribution to selected industrial firms. $45,000 in FY 1965 funds were committed for this contract which is to be let mid-way through the next report period.

SEMINARS

The seminars presented at JPL by Professor R. Viskanta during the summer of 1964 have been published in a JPL internal document titled Definitions and Basic Laws of Thermodynamics and Physics of Radiation.

During the report period Professor Phillip F. O'Brien of UCLA presented a seminar series at JPL on radiation heat transfer. The series was adapted from a two-week course titled "Luminous and Thermal Radiative Transfer" to JPL temperature control nomenclature and sample problems. The course, which described computer analysis of heat transfer between specular as well as diffuse surfaces, was attended by all temperature control engineers in the Engineering Mechanics Division and several design, facilities, propulsion and systems engineers. The course notes are to be assembled in a JPL internal document.

SPECTRUM RESEARCH AND SIMULATOR ERROR STUDY
NASA Work Unit 124-09-05-04
JPL 324-90701-2-3750

During January, the Eppley Laboratory completed Purchase Order 950929 and delivered two single-channel filter detector modules and one dummy mockup of the 12-channel filter detector block to this Laboratory. The single channel modules were environmentally tested to the Mariner type approval vibration, shock, and acoustical exposure levels with no apparent damage or change in the sensitivity of the filter detectors. During this same time period, a breadboard of the electronic signal conditioning equipment was fabricated and tested. Full system operation of the breadboard and dummy mockup filter detectors was first accomplished in March 1965.

The solar spectrum measurement experiment (SSME) breadboard system has been used during the past few months to investigate the suitability of various types of light sources for X-15 preflight and postflight checkout, test the performance of the system over the anticipated temperature range, and set the system data rate to be compatible with the X-15 recording facilities. During the initial test of the new JPL 10-ft space simulator, the SSME detector was placed in the beam for a six-hr period and exposed to various light levels. The intent of this experiment was to determine the change in tare radiation produced by filter, lens, and body of the block. Though the temperature of the block increased from approximately 23 to 52°C, the worst observed zero shift was only about 20-μv , or 5% of the detector output.

Concurrent with the above testing, a packaging and mechanical design effort was undertaken. The packaging of the electronic signal conditioning equipment is complete and procurement of the necessary components, commutator, amplifier, and power converter has been started. The pod-hatch and erection mechanism design is approximately 80% complete. The complexity of this mechanism is such that complete detail design is not possible until certain inertial loads and reactions are determined experimentally; to this end, an in-house fabrication effort has been initiated. A comprehensive status report of this project was prepared and delivered to NASA-OART in June 1965.

In the immediate future, the SSME breadboard system will be taken to Edwards for an X-15 mating test. The intent of mating the breadboard with the X-15 power supply is to make certain that the ripple and noise of the X-15 dc supply will not seriously degrade the data, and more importantly, to determine that the noise inherent in the SSME dc-dc converter will not interfere with the X-15 communication systems. A vacuum test in the JPL SSA-8 solar simulation system will be made later this month. For this test, a simple mechanized shutter has been fabricated so that the dynamic response of the instrument system can be evaluated under simulated X-15 flight exposure conditions. A calibration test at Table Mountain is planned to complete testing of the breadboard equipment.

In preparation for the X-15 flight, negotiations with the Eppley Laboratory for the fabrication of the flight filter detector system are underway, and it is planned to start fabrication of this item as soon as possible after July 1, 1965.

Procurement of this filter detector, the flight signal conditioning equipment, and the in-house fabrication of the pod-hatch and erection mechanism will be the major activity during the next few months. Preparation of the test plans for environmental evaluation of this equipment for an X-15 flight in the fall of this year is under way with a flight tentatively scheduled in late September.

JPL Technical Memorandum No. 33-243, Vol. II

OPTICAL PROPERTIES OF TEMPERATURE CONTROL SURFACES
NASA Work Unit 124-09-05-08
JPL 324-91101-2-3510

Three technical objectives were set forth at the beginning of this program:

1. To improve capability to measure directly total hemispherical emittance of temperature control surfaces.

2. To determine optical properties of temperature control surfaces at oblique angles of incidence.

3. To improve the capability of spectro-photometric equipment to measure optical properties in the solar region.

The first objective has been met as completely as a year's time will allow, and has produced consistent data for a number of materials and a successful automatic data acquisition system. A computer program to yield emittance results from rigorous radiant heat exchange equations has recently been formulated. Preliminary results show that the approximate equations which have been used in the program for samples at room temperature have apparently been sufficiently accurate.

The data acquisition system is a Dymec DY-2010 which produces printed tape for data reduction to yield emittance values. This system consists of a digital voltmeter, a preamplifier, a program sequencing unit and printer. The system was operated for several months in parallel with the manual, which used a L & N K-3 potentiometer with standard cell, and voltage comparisons were made to indicate the departure of the automatic system from the manual. These differences indicated voltage equivalent differences of about 0.1°F. The schematic of the automatic data system is as shown in Fig. 1. The complete emissometer system is depicted in Fig. 2 and 3. Up to the middle of May, 51 sample runs had been made of emittance of coatings.

By use of the physical modifications of the heat exchange equipment introduced last year, we have, during the report period, been able to reduce sample temperatures to the temperature region between -200 and -100°F and to measure the emittance as a function of temperature. Only a few materials have been examined in the low-temperature regime, and shown in Table 1.

Table 1. Measured low-temperature hemispherical emittances

Material	ϵ_H Room Temperature	ϵ_H Low Temperature
ARF-2 (Zn0 silicate)	0.93 (83°F)	0.73 (-137°F)
Flat black paint	0.88 (72°F)	0.80 (-166°F)
Aluminum silicone	Unchanged from room temperature	Unchanged from room temperature

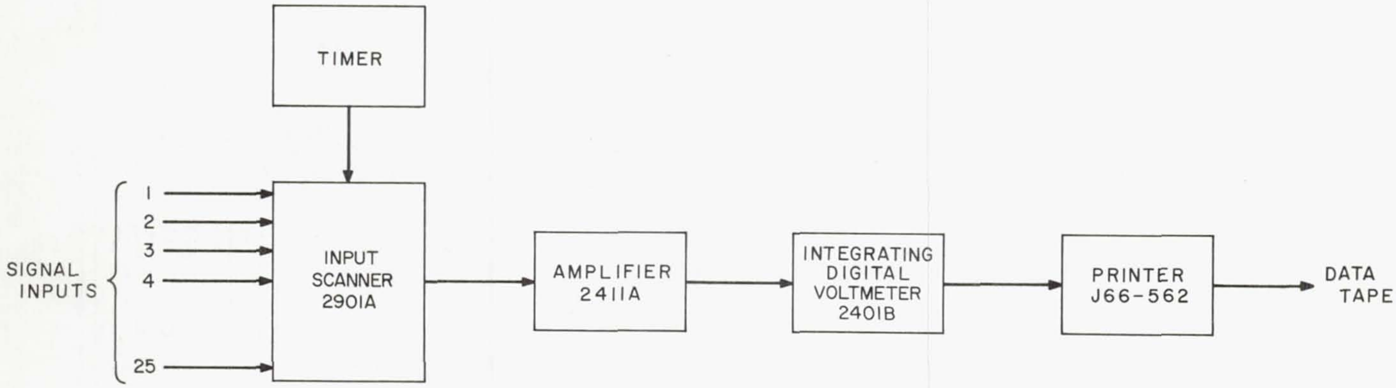


Fig. 1. Schematic of digital data acquisition system

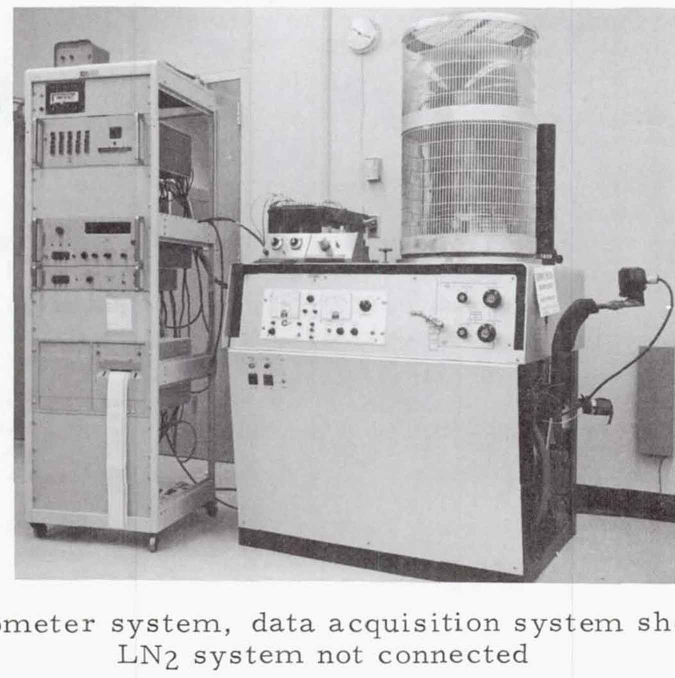


Fig. 2. Emissometer system, data acquisition system shown in rack at left; LN_2 system not connected

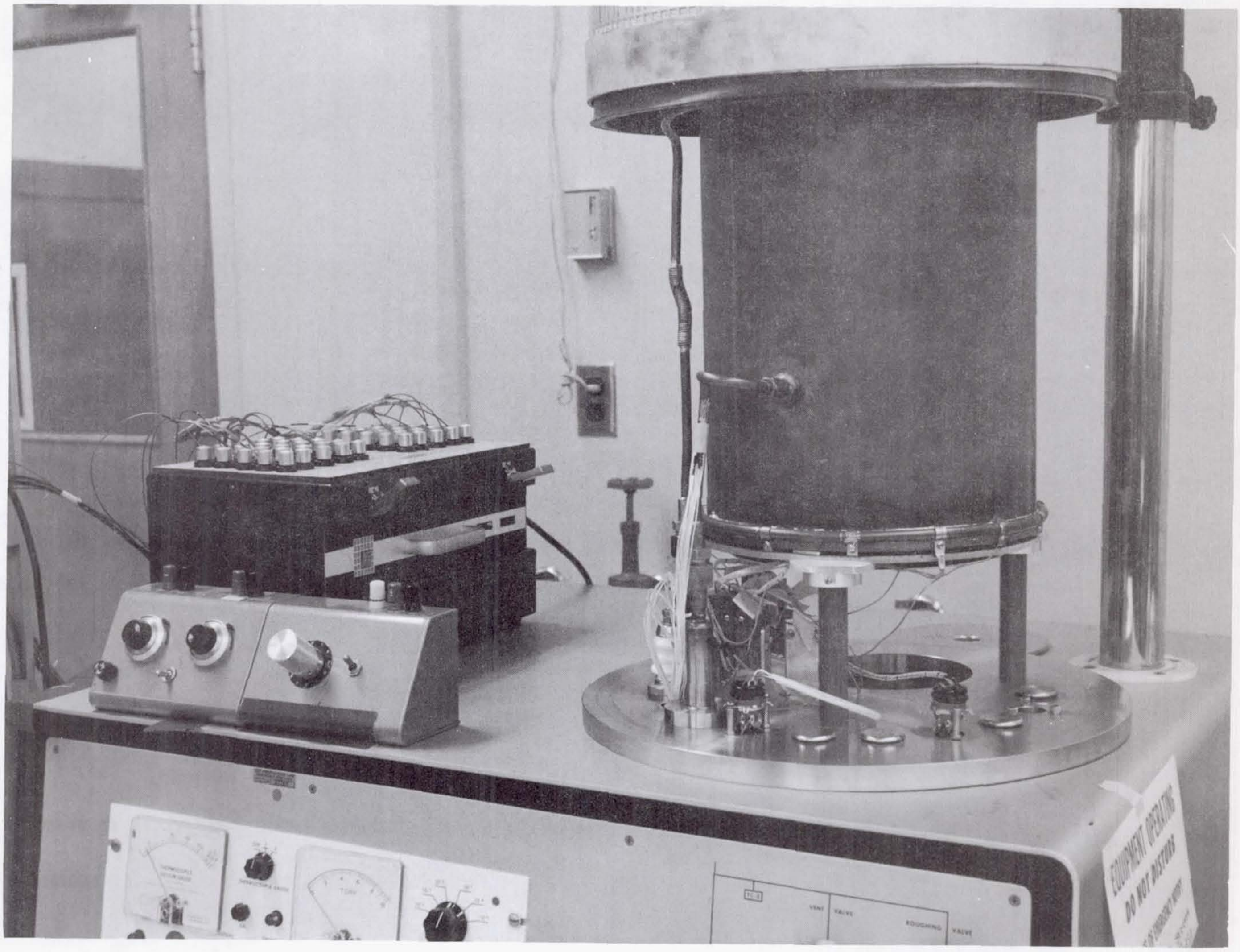


Fig. 3. Emissometer system; showing details of LN_2 cold shroud and external details of sample mounting

The low-temperature investigation should be continued, as it will yield low-temperature engineering data not available from any other source.

The second objective has been met by a set of recently acquired spectral reflectance versus incidence angle values, measured by Space Technology Laboratories under JPL contract. A number of spacecraft paints and metal finishes were measured at 7 incidence angles from 10 to 85 deg. The measurements were made in wavelength increments corresponding to 2% energy intervals of the Johnson solar curve to facilitate calculations of the effective solar absorptance. The accompanying set of curves, Fig. 4, display these values as a function of the angle of incidence. The α_s value at any given angle represents the absorptance of a plane surface at the particular angle of incidence; the effective absorptance of curved surface would be calculated by summation of the absorptances of a number of plane areas, weighted by the subtended area.

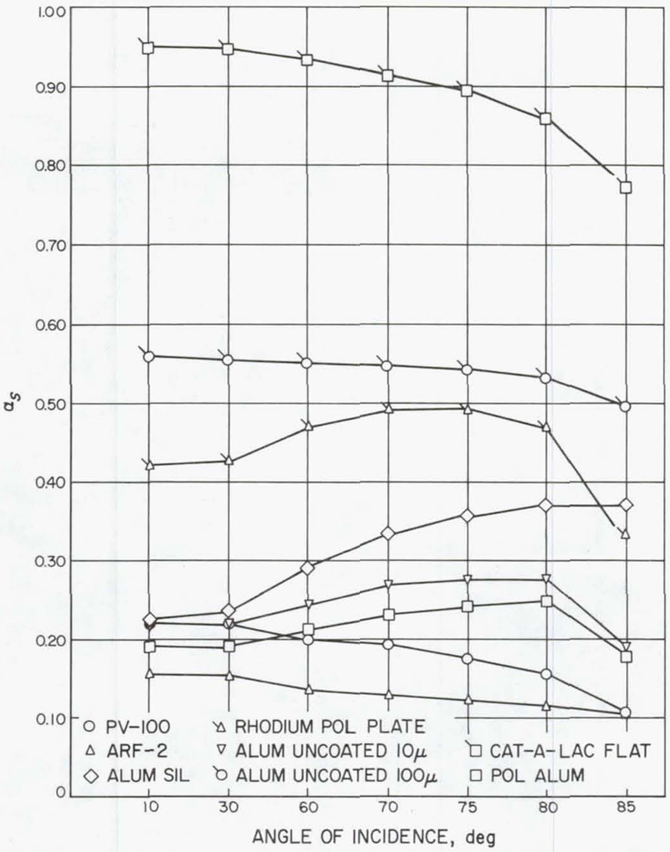


Fig. 4. Variation of solar absorptance with angle of incident radiation

It would appear that, for all of the finishes studied here, the normal incidence value of α_s is a good approximation out to about 30 deg incidence angle. For most of the finishes the departure of α_s from the normal value will change the temperature situation considerably at angles of incidence beyond 30 deg. Two examples of the change of α_s/ϵ_H value are listed for a large incidence angle.

Material	ϵ_H	α_s/ϵ_H (Normal)	α_s/ϵ_H (60°)	% Change of Ratio
ARF-2 White paint	0.9	0.176	0.151	- 16.6
Polished aluminum	0.05	3.86	4.26	+ 10.4

The third objective has not been met except for reviewing catalog literature of potential suppliers for synchronous amplifiers. There was not an adequate amount of time to carry out a proper performance examination of an amplifier purchased under this program when manpower allocations at JPL were revised, so no purchase money was expended for that purpose. It is believed that such a program would be valuable, especially if performed in conjunction with examination of low noise detectors operating at cryogenic temperatures.

SPACE VEHICLE DESIGN CRITERIA (124-12)

STRUCTURAL DESIGN CRITERIA
NASA Work Unit 124-12-01-01
JPL 324-20101-2-3530

SPACE-VEHICLE DYNAMIC LOADS FOR THE LAUNCH AND EXIT PHASE

A contract was awarded in late June 1965, to General Dynamics/Convair for the preparation of an engineering manual on dynamic loads criteria and analytical techniques for space vehicle systems during the launch and exit phase. In planning for direct participation in this activity, JPL has obtained an applicable computer program from GD/C, and has integrated this program with a JPL program based on techniques described in JPL Technical Report 32-350, Dynamic Analysis of Structural Systems by Component Mode Synthesis.

In supporting this effort, JPL will prepare a companion document to GD/C's engineering manual. This document will emphasize improved techniques for the technical management of the dynamic-loads analysis of complete space vehicle systems, the separate stages of which are assigned to different NASA centers and contractors. The Atlas/Centaur/Surveyor system will be used in illustrative applications. JPL will compute sets of normal oscillation modes of the entire system from suitable mathematical models of the Atlas and Centaur stages (provided by GD/C) and the Surveyor spacecraft (provided by Hughes Aircraft Company.) GD/C will use these modes as generalized coordinates in analyses of system responses to transients associated with thrust buildup or tailoff, stage separation, gust encounterment, etc. Completion of all phases of this effort is expected in June 1966.

ENGINEERING MANUAL ON MODAL VIBRATION TESTING

It is planned, as an in-house effort, to compile an engineering manual on the theory and practice of modal vibration testing, with a section devoted to the role of this type of vibration testing in the overall program of structural-dynamics investigations of space vehicle systems. Free reference will be made to documentation on design and performance criteria for modal-vibration-survey equipment.

CONTROL CRITERIA FOR MULTISHAKER SYSTEMS

During FY 1965, JPL conducted, under project funding, some theoretical investigations into the nature of the voltage control problem associated with the use of multiple electrodynamic shaker systems for random vibration testing of spacecraft or large assemblies. Illustrative numerical analysis has been directed toward a simple structure (a uniform beam) under random excitation by two asymmetrically placed shakers. In FY 1966, this work will be completed under the subject task. It is planned to explore the application of the analog computer to the generation of voltage-control tapes for both band-limited random vibration, and for discrete transient responses. It is also planned to perform tests for these cases using a simple beam as a test specimen. The results of the entire activity will be published in appropriate JPL documents.

For FY 1966 the title of this task is changed to "Structural-Dynamics, Design and Test Criteria".

ELECTRONICS SYSTEMS (125)

Page Intentionally Left Blank

GUIDANCE SYSTEMS (125-17)

INERTIAL SENSORS - GAS BEARING GYROS
NASA Work Unit 125-17-01-01
JPL 325-70101-2-3440

HIGH SCALE FACTOR AND TEMPERATURE COMPENSATED TORQUE

This development effort is directed toward increasing the torquer scale factor and time and temperature stability of the Honeywell GG159 gas bearing gyro to simplify system applications. The existing torquer is a 2-pole configuration with a scale factor of 85 deg/hr/ma and no temperature compensation. The temperature sensitivity is approximately 0.12% over the range from 75 to 105°F. Increasing torquer scale factor to 300 deg/hr/ma will reduce the attitude control package weight for existing type systems by approximately 2 lb. Improved temperature stability may reduce calibration requirements.

The new configuration design phase is completed and some verification breadboard tests have been conducted with good results. The new calculated scale factor is 300 deg/hr/ma and temperature sensitivity is 0.007% over the range from 75 to 105°F. Figure 1 shows the torquer and signal generator configuration, and Fig. 2 shows the torquer temperature sensitivity.

HIGH FREQUENCY PUMP AND SUSPENSION SYSTEM

This effort was directed toward the development of a high-frequency pump and gimbal suspension system that meets turning rate and g capability requirements of anticipated advanced space gyro applications.

The GG159C gas spin bearing gyro uses a hydrostatically supported gimbal with the flotation fluid circulated by a fluid pump (Fig. 3). Current production gyro pumps operate on 12.5-to 30-cps excitation frequency and require from 1.0 to 1.5 w of power. The piezoelectric pump developed under this contract operates with 100 v at 400 cps and has a power requirement of 0.2 w. It consists of a dither plate and a stationary plate, each having an orifice oriented in series to provide a rectified fluid flow large enough to support the proposed suspension system. Fig. 4 shows a test mockup used to evaluate a breadboard pump.

The gimbal suspension system was designed to meet sterilization and high-g requirements while simultaneously fulfilling a steady-state 15-g support and 15,000-deg/hr output axis turning rate requirements with a satisfactory low gimbal damping. The damping varies from 440 dyne-cm-sec at 130°F and 1770 dyne-cm-sec at 50°F.

The possibility of using a rotary magnetic pump was also studied simultaneously with the piezoelectric pump to determine which configuration is best from a consideration of power, simplicity, and size. The piezoelectric pump is superior in all respects.

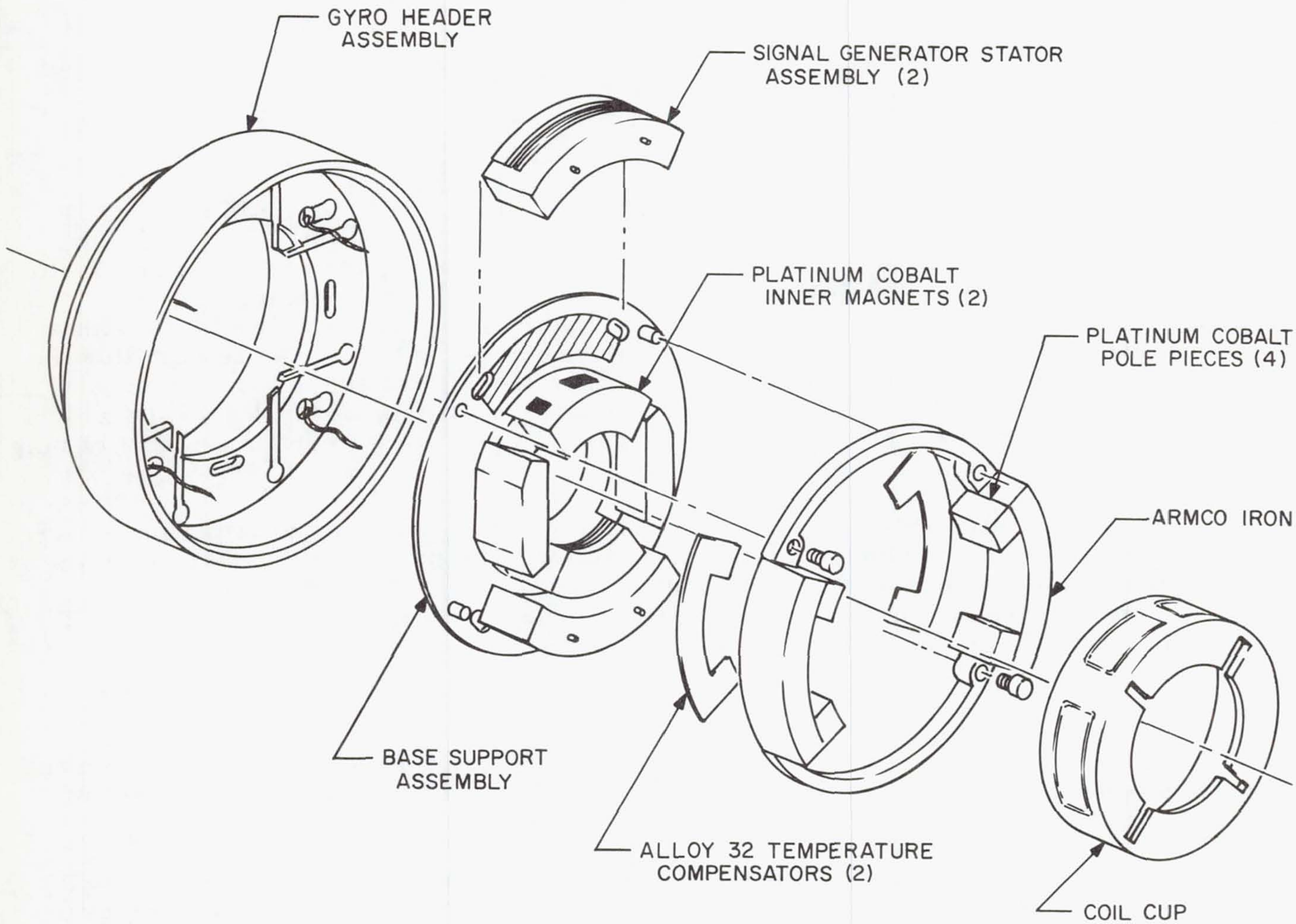


Fig. 1. Pictorial representation of GG159 4-pole torquer-signal generator assembly

FUTURE PLANS

The high frequency pump and torquer scale factor improvement designs are completed and the next step is to build and evaluate gyros with these improvements incorporated. This is planned for FY 1966.

A gyro built under this contract has been delivered and is undergoing evaluation under the Voyager program effort. This gyro has the high-g capability improvements. The evaluation program is being reported on in the SPS.

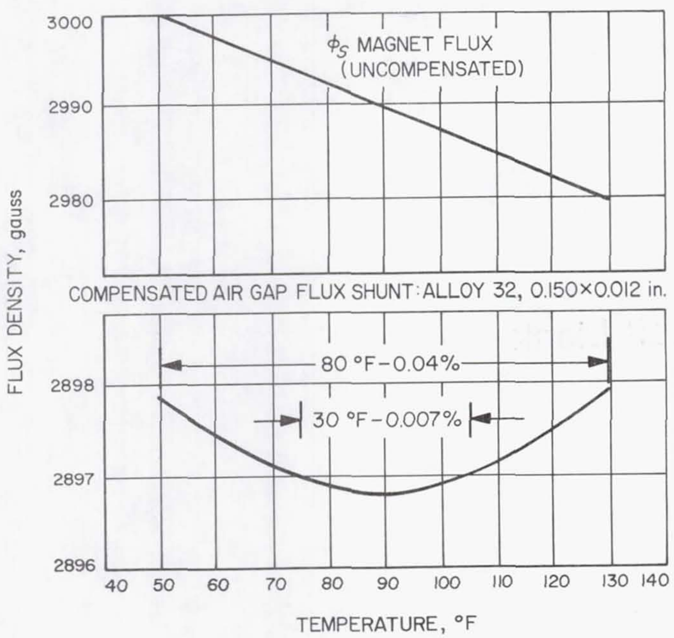


Fig. 2. Temperature-compensated air gap flux

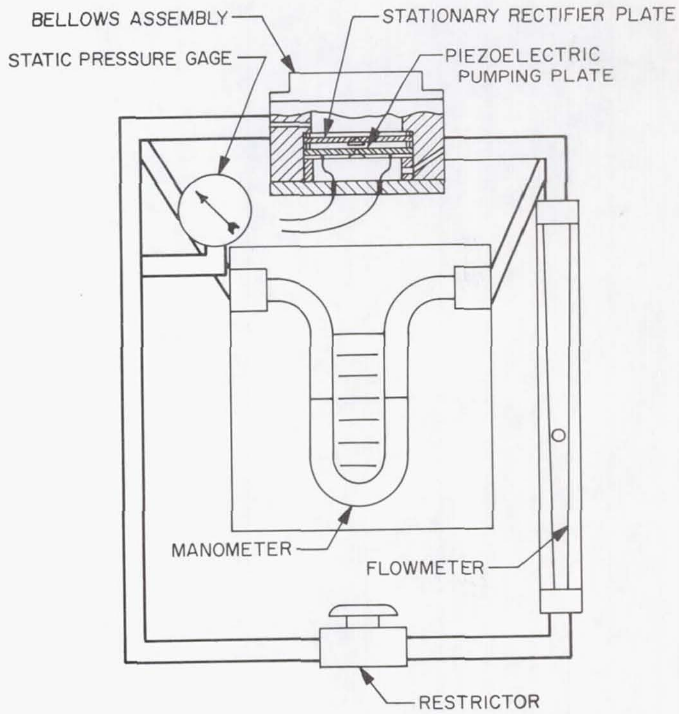


Fig. 4. Piezoelectric pump test mockup

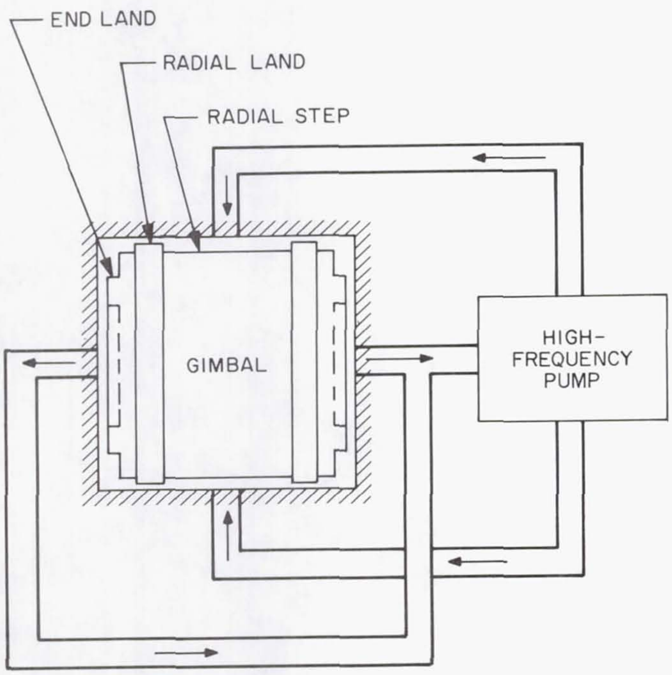


Fig. 3. Gimbal suspension system

Page Intentionally Left Blank

INERTIAL SENSORS - ELECTROSTATIC GYRO
NASA Work Unit 125-17-01-02
JPL 325-70501-2-3440

The electrostatic gyro effort has been concerned with contract negotiations. On June 4, 1965, two contracts were released: (1) to complete the fabrication of a gyro and conduct an extensive evaluation program and (2) to build another identical gyro.

The evaluation will include some subcomponent modifications and electronic adjustments before performance tests are started. Some of the evaluation tasks are as follows:

1. The suspension system will be evaluated in the 4g and 15g modes. The phase and amplitude response will also be determined under vibration.

2. The readout system will be evaluated in the gyro to determine the sensitivity to rotor noise, trigger uncertainty, illumination variation, reflectance variation, and pickoff attitude vs pattern velocity direction. Pickoff alignment capability will also be established.

3. Drift runs will be conducted to determine the performance coefficients in a variable magnetic and thermal environment.

4. Spin up and damping tests will be conducted to determine starting time, thermal stabilization time, and the effects of housing angular rates on starting.

5. A computer program is being written to reduce the performance data.

6. Specialized control consoles and a data recording station are also being fabricated.

Page Intentionally Left Blank

INERTIAL SENSORS - SPACECRAFT CONTROL GYROS
NASA Work Unit 125-17-01-03
JPL 325-70601-2-3440

VIBRAROTOR GYRO

A vibrarotor gyro (Litton Industries) was delivered to JPL in June 1965 after being evaluated by the contractor. As delivered, the gyro does not meet all performance requirements. The gyro was delivered to JPL even though all specifications were not met. It is felt that greater knowledge of the potential of this gyro could be obtained by conducting further evaluation at JPL. JPL tests will begin as soon as some contractual agreements are made with the contractor.

Some test results furnished by the contractor are shown in Table 1.

Table 1. Vibrarotor gyro test results

Coefficient	Specification, deg/hr	Test results, deg/hr
G insensitive	3.0	0.69
G sensitive	0.2	3.61
G^2 sensitive	0.5	0.14
Random drift	0.05	0.01

STAR GYRO

The overall development goals under a contract with Autonetics are to determine theoretically, with experimental support, the best general design configuration for torquing and to develop an error model that will pinpoint the important error sources and thus show the limitations (both in type and magnitude) under which the string angular reference (STAR) gyro can be torqued.

The STAR gyro operating principle uses a quartz string attached at both ends and forced to vibrate transverse to its axis. Ideally, the transverse vibration plane is inertially fixed independent of string rotation about its axis. Thus, case mounted pickoffs sense rotation about the string axis and provide attitude information to an inertial reference axis.

The final report is being written now. This semiannual report is a summary of the more important results achieved in the study effort.

The major accomplishment has been the development of a quite-comprehensive theory for the response of the vibrating string to applied torquing forces. The emphasis in this development has been on the response in second-mode operation.

It has been discovered that, by properly choosing the time form of the torquing force, it is possible to torque a string gyro without inducing subsidiary harmonics, subharmonics, or elliptical-component motion. It has been further verified that torquing sensitivity, in the second mode (as in the first), is directly proportional to force amplitude and inversly proportional to string amplitude.

An expression has also been obtained for the errors introduced to the torquing scale factor by phase shifts in torquing-pulse timing. This expression shows the effect of three components of possible timing phase errors.

Experimental activity was aimed towards accumulation of STAR torquing data using the laboratory setup. Considerable instrumentation to monitor the mechanization has been provided to verify the stability of various portions of the circuits, and to determine the accuracy to which critical parameters can be held and to which the output data can be obtained.

During the report period, numerous torquing runs were taken. Data has been recorded while varying four different parameters. Torquing pulse rate, torquing pulse phasing relative to string velocity, torquing pulse amplitude, and torquing plate dc bias have been changed. To date, the experimental evidence substantiates the results expected from theoretical studies.

Of interest are the following details regarding the laboratory results. The test instrument has been repeatably torqued in excess of 2000 deg/hr. Torque pulse scale factors have been varied from less than 1/10 to greater than 1/2 arc sec/pulse. Torque pulse rates have been varied from zero rate to a rate equal to one-half of the string frequency. Temperature sensitivity runs have been conducted.

JPL has been supporting the STAR gyro torquing study while the Air Force and Autonetics have been supporting the basic instrument development. Preliminary results from the torquing study indicate no basic limitations in achieving satisfactory results. However, the instrument itself is very sensitive to vibration, which appears to be one of the pacing development milestones at this time. An intensive effort is underway at Autonetics to solve this problem which should be completed in mid-Summer 1965. At that time JPL will reevaluate the entire STAR gyro program to select the most logical development areas for further support, not necessarily further torquing studies.

MAGNETIC LOGIC COMPUTER DEVELOPMENT
NASA Work Unit 125-17-04-01
JPL 325-70201-2-3410

PROGRESS

The complete engineering model of the inhibit core logic computer has been integrated and tested. A discrete-signal output system has been connected to the rest of computer. This system is capable of operating relays, electronic switches, or silicon controlled rectifiers. A triangular matrix of transfluxors operated in an NDRO mode provides the stimulus to the appropriate output device. Addressing is done with a spatial 2 out of 19 code.

Several circuit improvements have been made, particularly in the inhibit-current source drivers, transfer circuits, and current steering switch drivers.

Two responsive bids for fabrication of modular packaged transfer circuits have been received and are being evaluated.

Experiments have been conducted in the encapsulation of ferrites in hard plastics without an intermediate freeze coat. Two forms of the same plastic are being investigated with the higher temperature cure material showing the more promising results.

The inhibit core logic CC&S memory, access, and sensing circuitry has been integrated and tested over the required temperature range.

Stanford Research Institute (SRI) has presented six seminars at JPL and has made significant improvements in the computer program modeling of the switching of a loaded core by including the elastic spike at the epoch of switching. Two papers reporting work supported by contract with SRI were presented at the Intermag Conference in April 1965.

PLANS FOR NEXT PERIOD

A program representing various phases of a typical planetary encounter/orbit mission will be executed on the inhibit core logic computer to obtain computing time and power profile data.

A contract for the development and fabrication of transfer circuit modules will be initiated. The solicitation for bids for the packaging in modular form of the core-rope logic memory will be started.

Experiments in ferrite encapsulation will be continued and a complete NDRO transfluxor memory plane will be packaged to determine the effects of encapsulation without use of a freeze-coat.

The input-output portions of the inhibit core logic CC&S will be developed and changes to the existing logic will be formulated to develop the capability of generating cyclic output switching signals.

The SRI contract will be extended with FY 1965 to continue the study of flux switching and computer modeling of core switching in the soft-state. Voltage switching will be studied and computer programs to determine core parameters from tabulated experimentally-derived data will be developed.

GUIDANCE COMPUTER ORGANIZATION
NASA Work Unit 125-17-04-02
JPL 325-70401-2-3410

SELF-REPAIRING GUIDANCE COMPUTER

The results of an investigation of operand encodings for the self-repairing guidance computer have been published as JPL Technical Report No. 32-711, A Study of the Effectiveness of Fault-Detecting Codes for Binary Arithmetic by A. Avizienis (May 15, 1965). A summary of this work was presented at the Symposium on Information System Reliability of the 1965 Congress of the International Federation for Information Processing (New York City, May 24-29, 1965), and will be published in the Proceedings of the Congress. The complete results will be prepared and submitted for publication in scientific literature.

The system and logic design of a diagnosable arithmetic processor is nearing completion. The processor is byte-organized, using a four-bit byte as the unit of information. The operands are encoded in a product code, using the check factor 15. The components for the arithmetic processor have been received and fabrication of a breadboard model has been started. The components selected for the breadboard model are Motorola MECL integrated circuits and General Micro-electronics' monolithic metal oxide semiconductor shift registers. The breadboard model will serve both for system studies and the evaluation of the integrated circuits. Completion and evaluation of the breadboard is planned for the next 6 mo.

The system design of the entire self-testing and repairing computer has been initiated. The block diagram for information flow has been completed. A complete system block diagram will be finished during the next 1/2 yr, and logic design of the checker and the central control will be started.

A contract for feasibility study and design of a magnetic connection switch to connect the various replaceable subunits of the computer to the information bus lines has been negotiated with Stanford Research Institute. Final signature approvals by all parties concerned are not yet complete.

MODULAR REDUNDANCY

A portion of the redundant sequencer designed to Mariner IV specifications has been selected for implementation. It includes the clock, the divider chain, and a representative set of relay outputs, as well as the power supply. About one-half of the sequencer will be built.

The primary purpose of investigating real equipment, rather than simulating it, is to verify how well the mathematical model approximates the circuitry. For instance, the model assumes that all signals from the channels arrive at a voter simultaneously, thus obviating the possibility of a hazard. The model also assumes that the outputs from a channel are always exactly one or zero and never some intermediate state. The model also is unable to take any account of problems that may arise from transients in the power supply. Any failure of a component may also cause transients that are not considered in the model.

The counters in the divider chain have memory and a transient error may cause them to get out of step. Resynchronization logic has been included to prevent such a counter from being permanently wrong. This resynchronization is not instantaneous and a study of this phenomenon is also to be made. It is important to note that this breadboard will be made of relatively good parts but is not intended to use 100% screening or testing or the other techniques that are essential to obtain a system with maximum reliability in the present state of the art. One reason for this is that the use of a breadboard fabrication technique itself precludes the results being significant in predicting the reliability of flight hardware based on the same logic. Therefore, it is not intended that this breadboard shall be used in tests intended to establish some statistically significant lifetime -- even if such a thing is possible with a sample of one.

The subcontract for breadboard construction has been negotiated and is now in the process of being approved by both parties. It is expected to take about 1/2 yr to complete after the effective start date.

An effective method for assigning locations to majority voters in modularly redundant digital systems has been devised. Based on dynamic programming techniques, and suitable for implementation on a digital computer, it is an outgrowth of a study of the similarly directed isolating array synthesis procedure developed at Westinghouse Electric Corporation.

If the increase in the size of a system over its nonredundant version is limited, the improvement in reliability realizable from modular redundancy is a complex nonlinear function of the location of voters within the system. To determine, in a straight-forward manner, the set of locations that yields the maximum improvement involves examining an impractically large number of alternatives. This new voter allocation method, called the dynamic synthesis procedure (DSP), drastically reduces the number of network comparisons needed to find the best or nearly best configuration.

The principle of optimality, the basic concept in dynamic programming, is not strictly adhered to in the voter allocation problem. Nevertheless, while the maximum reliability improvement is not guaranteed, the DSP should often achieve it. Even when it doesn't, however, the improvement should be sufficiently great to justify its use. Because of the imbedding process inherent to dynamic programming, the behavior of the system reliability function as the number of voters is varied can be easily observed. Thus, a means for comparing system size (power, weight, etc.) and reliability is available. At present, the order of redundancy throughout the system being synthesized must be kept constant, but the procedure is potentially capable of handling variable degrees of redundancy. The DSP should be applicable to much larger problems than the Westinghouse procedure.

Detailed flow diagrams of the DSP have been completed. Coding of the procedure for the IBM 7094 is to start shortly.

OTHER WORK

The NASA - OART subprogram 125-23 has a contract with the Westinghouse Electric Corporation for the study of failure free systems. This work, in progress for about 2 yr, is of interest in connection with the present work unit and has been closely followed. A visit was made to the contractor during the present reporting period and progress was discussed at NASA Headquarters with the representative in charge of the contract.

The NASA Electronics Research Center is also working in the field of ultra-reliable computers and a visit was made to this organization to exchange information regarding the respective efforts.

Page Intentionally Left Blank

GUIDANCE STUDIES FOR FUTURE MISSIONS
NASA Work Unit 125-17-05-01
JPL 325-70301-1-3430

LANDER GUIDANCE ANALYSIS

Two computer programs have been developed (and documented in Guidance and Control Technical Memos 343-51 and 343-55) for the analysis of the atmospheric entry and landing guidance for a capsule or spacecraft. The first program determines the approach orbit aiming point in the plane perpendicular to the approach asymptote required for impact on the planet at a specified time and location. The second program determines the impact location when the approach trajectory is given. Both programs include the effects of the atmosphere on the path of the entry vehicle. These programs are to be used for the analysis of the affect of the guidance system accuracy on the impact location or to convert impact location requirements to approach trajectory accuracy requirements.

GUIDANCE REQUIREMENTS FOR FUTURE MISSIONS

During FY 1966, the guidance requirements for several planetary missions of interest will be studied; and the applications of approach guidance to these missions will be investigated. The missions to be studied either are possible extensions of the Voyager project or are expected to be the subjects of JPL advanced technology studies in the next few years (please refer to the material in this document reporting on NASA Program 684 for advanced technology studies plans). The missions include:

1. An accurately-controlled entry and landing at Mars.

2. Probes to investigate comets and asteroids.

3. A Jupiter probe.

4. A Mercury probe with a trajectory profile that includes a major perturbation by the gravitational field of Venus.

An initial survey will be made of the guidance requirements of each mission listed above. The purpose of the survey is to bound the guidance task by establishing an initial quantitative estimate of the range of guidance requirements; to obtain an initial idea of possible system configurations to meet these requirements; and to develop the information on problem areas required to plan an effective detailed attack on the guidance task.

Following the initial surveys for each mission, the approach guidance requirements for the missions will be collected and compared to determine possible common approaches applicable to more than one of the missions; and parametric tradeoffs will be made. (Approach guidance refers to the guidance phase where spacecraft-based optical guidance measurements are made as the spacecraft approaches to within several millions of kilometers from the destination planet. The purpose of approach guidance is to refine guidance accuracy beyond that which can be obtained

with midcourse guidance using Earth-based radio tracking measurements alone.) This work is expected to occupy the major part of the first half of the fiscal year. During the second half of the fiscal year definition of possible system configurations and study of system integration problems is envisaged. In this latter task, the work will be coordinated with that performed under NASA Work Unit 186-68-02-21, Guidance and Control Subsystem Integration for Future Missions, e.g., the On-Board Computer Program study.

COMMUNICATIONS (125-21)

ELECTRICAL SYSTEM ADVANCED PACKAGING
NASA Work Unit 125-21-03-03
JPL 325-10501-2-3570

Three major tasks were engaged during the performance of this work unit:

1. Electronic packaging advanced development.

2. Microelectronic packaging advanced development.

3. Modular welded packaging advanced development.

In FY 1966 the three work areas are identified as separate work units; the newly assigned FY 1966 work unit numbers are referenced with the work unit title.

ELECTRONIC PACKAGING ADVANCED DEVELOPMENT (FY 1966 NASA WORK UNIT 186-68-10-05, JPL 384-65801-2-3570)

The translation of circuits and logical schemes for spacecraft electronic systems into physical realities that will perform reliability in the launch and space environments is the function of the electronics packaging discipline at JPL. The advanced development electronic packaging work completed to date within this task has contributed to the success of recent Ranger and Mariner flights. Present and future work will support the Surveyor and Voyager projects.

The objectives of this work unit are:

1. To identify new spacecraft systems electronic packaging and cabling requirements, and to develop and qualify new concepts that provide substantial improvements in future spacecraft.

2. To conduct study and research on the characteristics and effects of high voltage phenomena in the critical pressure region to gain technology to support a high voltage electronic equipment design specification.

3. To study, evaluate, and develop advanced interconnection techniques.

4. To develop nonmagnetic interconnect welding materials and technology.

5. To increase electronic circuit interconnect reliability.

Advanced Electronic Packaging and Cabling Concepts

During FY 1965, development work progressed on two highly reliable advanced packaging configurations. Each will be described in detail in the micro-electronic packaging advanced development and modular welded packaging advanced development work units.

In FY 1966, other advanced electronic packaging concepts will be studies and developed in support of Voyager and future spacecraft. A major effort will be to further investigate high density planar multilayer techniques and configurations that have higher inherent reliability and fewer problems than multilayer circuit board configurations.

A printed conductor ring harness was designed and developed to determine the feasibility of replacing the two upper ring harnesses and trough assembly in the Mariner IV PTM. Figure 1 shows the printed conductor assembly. This concept was based on the original work of substituting a printed conductor ring harness for Mariner R (SPS 37-24, Vol. 4). The Mariner R configuration was designed and fabricated, but it was not possible to system test the harness. In April, the assembly was tested on the Mariner PTM and the electrical performance was excellent, in fact it was considered flight acceptable.

The advantages of the printed conductor configuration, when compared to conventional harnesses are:

1. Lower weight.
2. Lower manufacturing cost.
3. Better rejection of high frequency electrical noise.

Based on the April PTM test, a few modifications are being made on the printed conductor assembly to improve the electrical performance. The modified assembly will be retested in August, and the resultant information will permit relative evaluation of the conventional wiring harness compared to the printed conductor configuration.

High Voltage Protection

High voltage corona and arcing discharge in the critical pressure region has been a very serious spacecraft design problem. The critical pressure region can be considered to be from 50 to 10^{-3} mm Hg.

In the past, most spacecraft electronic equipment using high voltages have not been designed to operate in the critical pressure region, and inadvertant high voltage turn/ons during preflight testing and during the boost phase of a flight have caused equipment damage. Recent development work has shown that electronic equipment using high voltages can be designed to operate through the critical pressure region with no resultant damage or degradation.

A preliminary specification for high voltage packaging design has been released that gives the requirements for designing, packaging, and testing of electronic equipment for spacecraft applications using voltages greater than 250 vdc

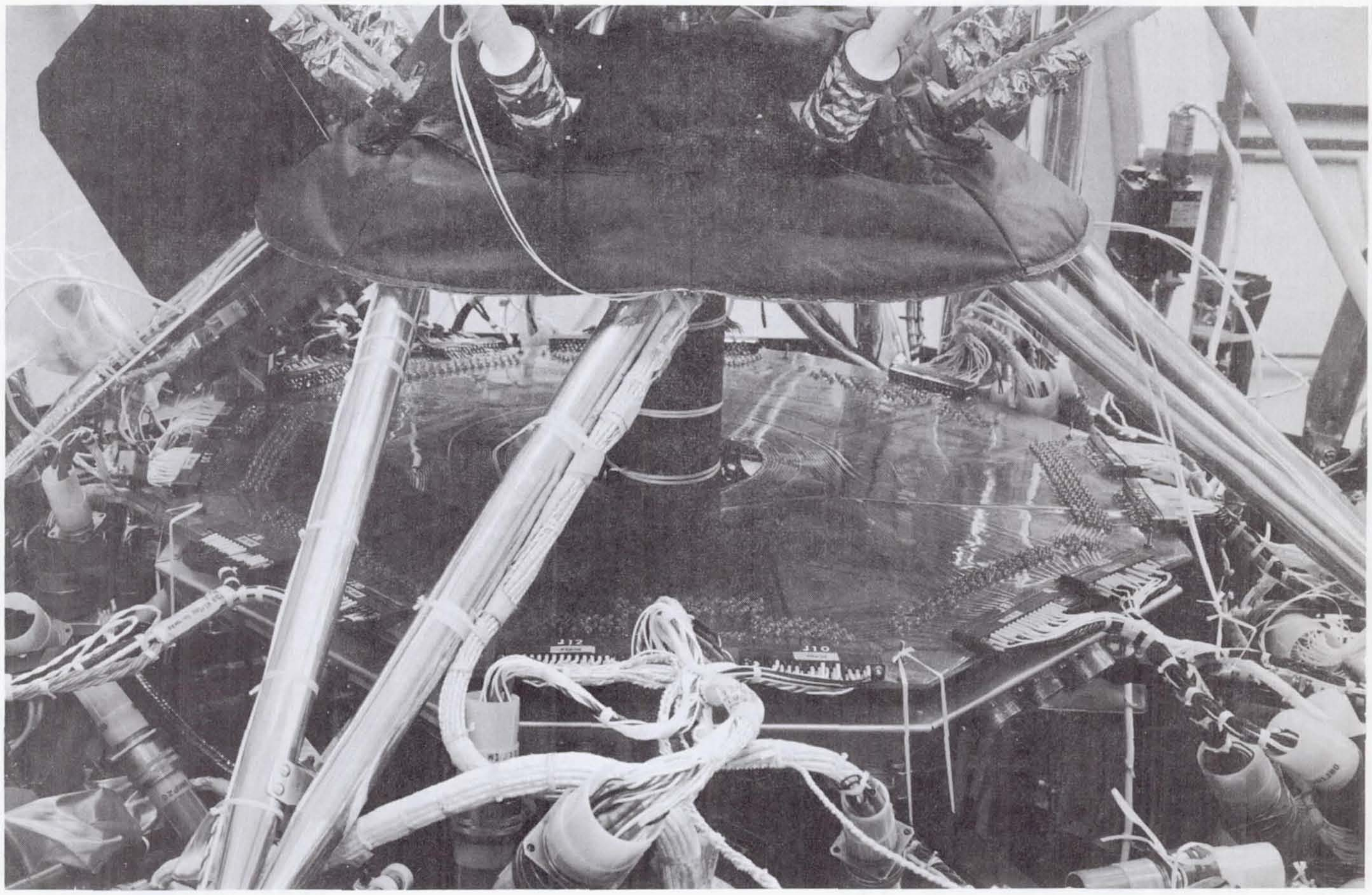


Fig. 1. Mariner C PTM upper ring harness printed circuit board

or peak vac. The additional study and development work planned will support the release of the specification.

FY 1966 development work will include the following tasks:

1. Improvement of sensitivity of series type corona detection network instrumentation design that is required to monitor electronic equipment during electrical testing at critical pressures.

2. Testing of various conformal coatings and embedment materials in the critical pressure region to further develop effective techniques for eliminating corona and arcing.

3. Develop component high voltage testing techniques and procedures.

4. Testing of additional geometries to further determine minimum distances for corona formation.

5. Further develop high voltage discharge trap techniques and designs required to protect electronic equipment elements that cannot be insulated by use of conventional techniques.

Welding Technology

The welding technology tasks have made substantial contributions to existing programs, and to the development of Voyager advanced development packaging efforts. The results of these tasks are reflected in the JPL Welding Process Specifications and the supporting process documents.

A recent development has been made in the area of Kovar integrated circuit flat pack ribbon lead welding. This type of weld has given the electronics industry trouble to date. We are in the final stages of development of a unique weldable terminal the parameters of which give a resultant weld that is:

1. Highly reliable.
2. Repairable with no degradation.
3. Extremely wide process margins.

Figure 2 is a photomicrograph of a Kovar lead parallel gap welded to the cupro-nickel terminal that has been developed. In FY 1966, the final development work will be completed.

Nonmagnetic interconnect media evaluation and development has been a major welding technology task in FY 1965. Nonmagnetic conductors are desirable in spacecraft design because of extremely low magnetic field requirements imposed by magnetometer experiments. Work is being done to increase welded joint reliability as an additional interconnect requirement to that of being nonmagnetic.

To date, palladium and a wide range of cupro-nickel alloys have been evaluated. Within the cupro-nickels, Alloy 90 (11% nickel) is an interconnect material that has shown much promise, and it will be used in the plasma experiment being developed at JPL for launch on an OGO-E satellite experiment in the near future. Figure 3 shows an Alloy 90 ribbon welded to a copper resistor lead. Figure 4 shows an analog to digital process welded converter module recently fabricated with Alloy 90 interconnect ribbon. In FY 1966, highly reliable nonmagnetic interconnect and component lead media will be developed further to additionally increase welded joint reliability through improved metallurgy and wider process margins. Silver/palladium and other binary alloys will be investigated, and developed if they prove feasible.

Recent development work at JPL indicates welding advantages associated with dynamically controlled square wave welding equipment. A relative evaluation will be performed in FY 1966 between the widely used capacitive discharge welders and the controlled square-wave equipment to investigate welding pulse control as a method of increasing weld process margins.

MICROELECTRONIC PACKAGING ADVANCED DEVELOPMENT (FY 1966 NASA Work Unit 186-10-03, JPL 384-66501-2-3570)

The integrated circuit devices that have been developed as products of microminiaturization programs are now achieving reliability factors approaching those associated with discrete semiconductor devices, and as a result the integrated circuits devices are being used more in satellite and spacecraft programs. The potential reliability gain is two-fold:

1. Gain in individual circuit reliability.

2. Gain in system reliability because of redundant subsystem functions made possible by the reduced power, volume, and weight requirements of the integrated circuit devices.

Fig. 2. 5 mil thick gold plated Kovar ribbon (top) parallel gap welded to developed cupro-nickel terminal

The development of packaging techniques and processes for the integrated circuits devices for space applications has not kept pace; as a result there are no known best packaging schemes suitable for spacecraft systems in existence that take full advantage of the integrated circuit size and inherent reliability.

The following three major objectives have been set for this task in support of Surveyor, Voyager, and other future spacecraft applications:

1. Design and development of advanced microelectronic packaging configurations.

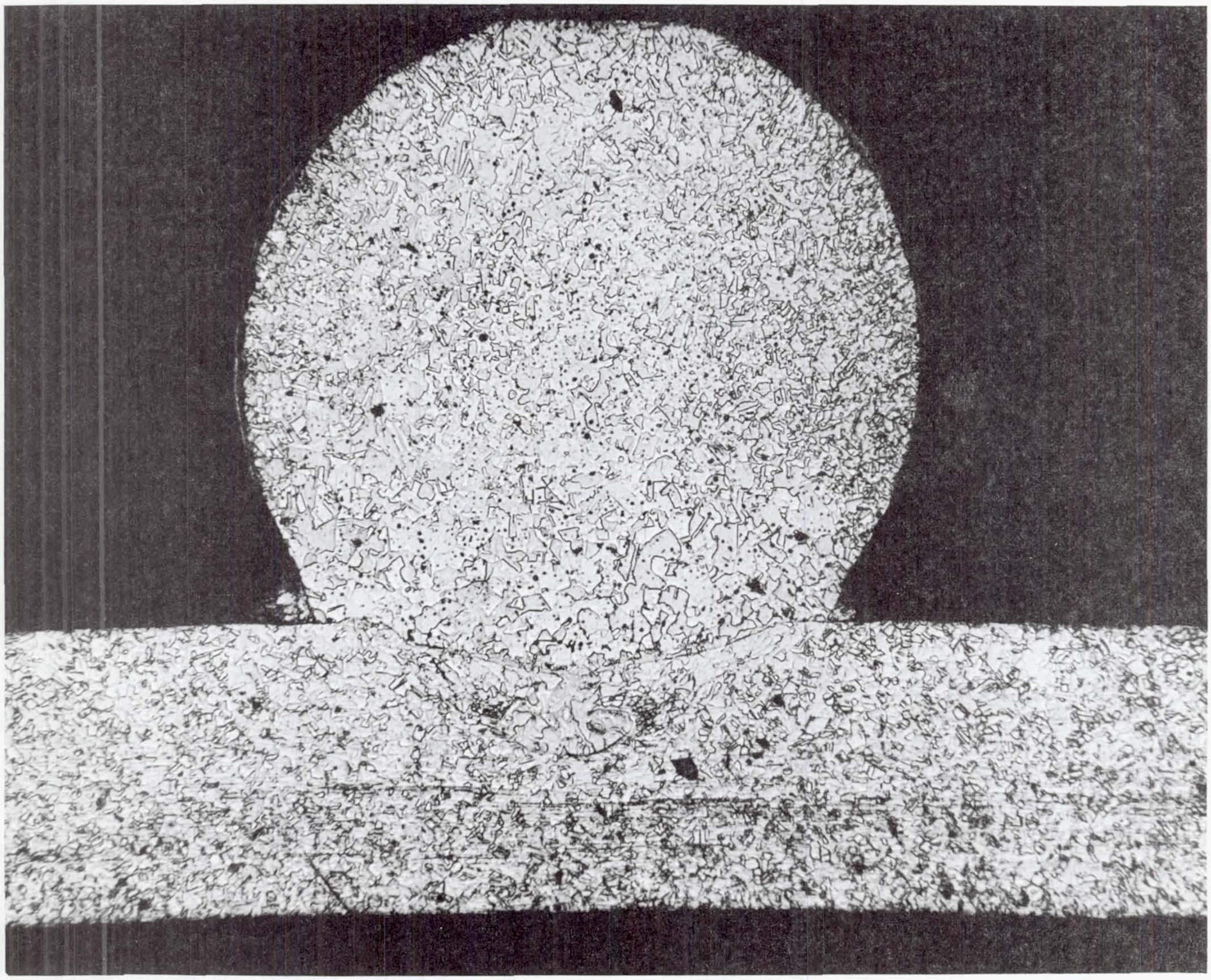


Fig. 3. 0.010 X 0.030 Alloy 90 (11% nickel, 89% copper) to 0.025 diameter tinned copper (ETP) (100X magnification)

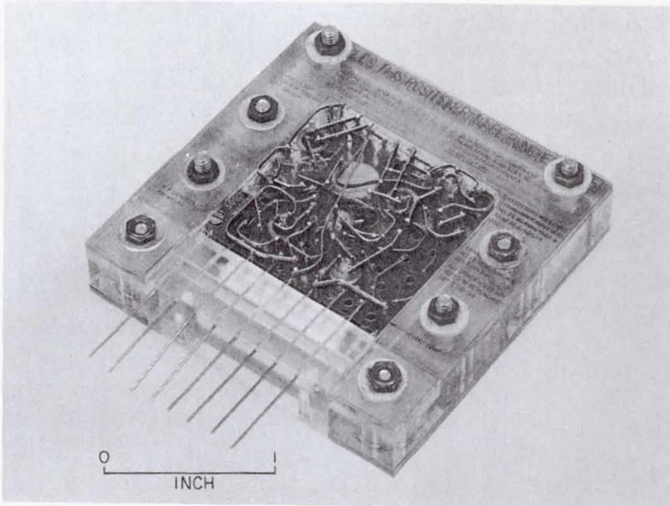


Fig. 4. Analog to digital process welded converter (Mark II) nonmagnetic interconnect

2. Study and evaluation of existing microbonding interconnection techniques, and development of more reliable techniques.

3. Study and evaluation of new developments in integrated circuit package techniques and configurations.

A unique configuration for integrated circuits packaging has been developed. This design is now being used in the packaging of approximately 300 integrated circuit devices for the programmer subassembly of a plasma experiment that will be carried by an OGO-E satellite. In FY 1966, this integrated circuit packaging configuration will be further developed and refined for Voyager.

Classically, high density modular assemblies have been developed with one common point of conceptional design that is questionable when the best design is required. There have been three dimensional interconnection requirements for both the discrete modules (welded cordwood, etc.), and the associated mother board interconnect assembly (welded wire matrix, multilayer circuit board, etc.). This dual requirement for planned three dimensional interconnection has resulted in larger numbers of joints than would be required by the best configuration for a given functional electronics assembly. Also, the three dimensional mother boards are difficult to reliably rework if required by a circuit change.

A stick module design concept was developed that decreased the numbers of total assembly interconnections and eliminated the requirement for a three dimensional mother board in high density modular assemblies. This concept was reported in SPS No. 37-26, Vol. 4. Basically, the concept that allows this improvement is a simple one. The three dimensional module concept was determined to be a vital feature from detailed study of all the tradeoffs. But, study showed always that the mother board interconnections could be reduced to single dimension parallel conductors. This simplification was developed by examining the total modular assembly in three dimensions and designing to obtain two dimensions of assembly level

interconnections within each module thereby leaving only a single dimension requirement to interconnect the modules at the assembly level. Figure 5 shows a flat pack integrated circuit module designed and built to satisfy two dimensions of assembly level interconnections, and the five times size modular interconnection stick that was developed.

In the summer of 1964, a fixed price development contract was awarded to Francis Associates to develop a process to reliably weld magnet wire through the insulation. The results of this effort were excellent. Figure 6 shows a sample board with weldable terminals on 0.050 in. centers randomly interconnected by welding through the magnet wire insulation. In anticipation of this new capability, magnet wire was applied to the modular stick concept and used to intraconnect terminals on the wiring side of the module by controlled soldering. In FY 1966, the welding technique will be developed further, and the soldering process will be replaced if reliability can be further increased.

Some of the more unique features of the integrated circuits stick module concept are as follows:

1. Use of insulated magnet wire for multilayer intraconnections at the discrete module level.

2. Nonmagnetic weldable and solderable terminals for high reliability repairable intraconnections.

3. Minimum design and fabrication time requirements.

4. Assembly level interconnections are one dimensional coplanar conductors.

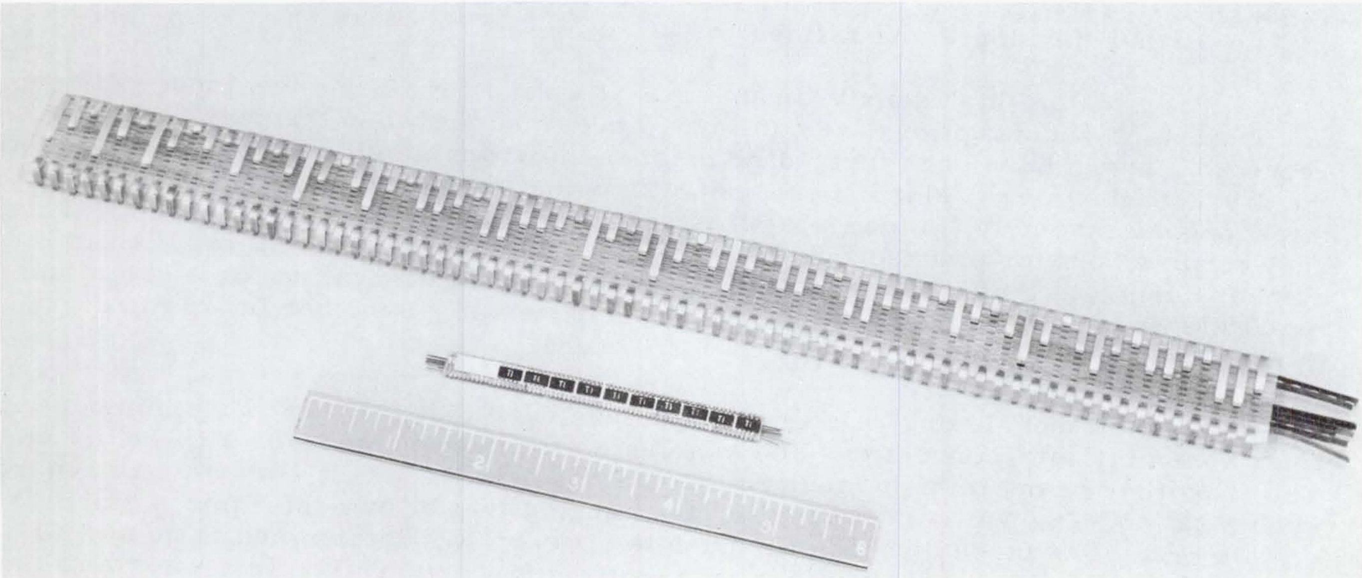


Fig. 5. Flat pack integrated circuit stick module initial development (5X size interconnect development module shown at top)

Figure 7 illustrates the module assembly concept in the current stage of development. The use of magnet wire was a design concept that has been studied in detail. The design benefits derived from this configuration were a high degree of freedom in designing and fabricating high density insulated multilayer intraconnections for the stick modules. Film insulation reliability was the major point in question when use of magnet wire was first considered.

Study has shown that the insulation is very reliable if certain precautions are taken:

1. Prevent the magnet wire from bearing on adjacent feedthrough terminals.

2. Conformally coat the terminals and magnet wires after all module intraconnections are completed.

The use of integral magnet wire guide studs ensures clearance between all terminals and adjacent magnet wire conductors for all routing conditions. A heavy double coating of urethane polymeric material satisfies the requirements of wire insulation for this application; it is highly resistant to abrasion and cutting, and when exposed to heat above 650°F, soldering or welding can be reliably performed because of the pulling back of the insulation and the inherent fluxing action of polyurethane.

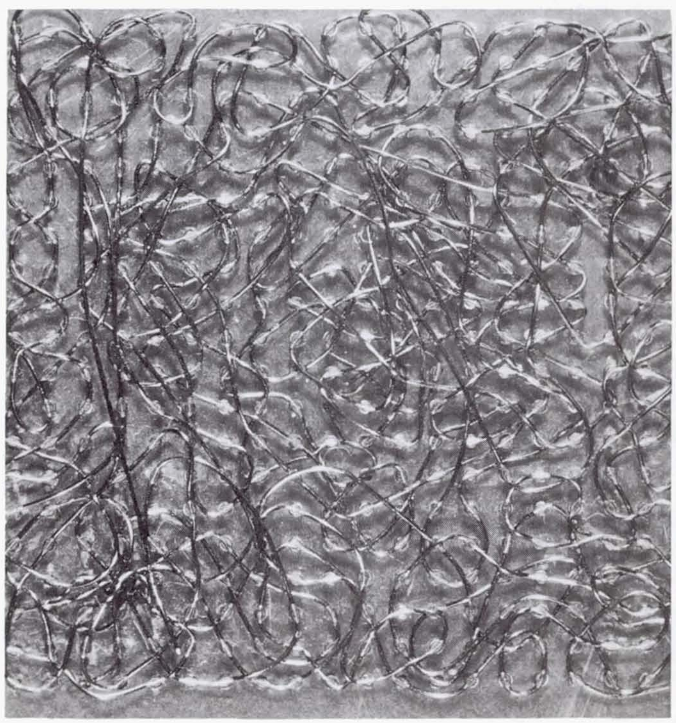


Fig. 6. Film insulated wire welded to Alloy 142 terminals (0.050 in. terminal spacing)

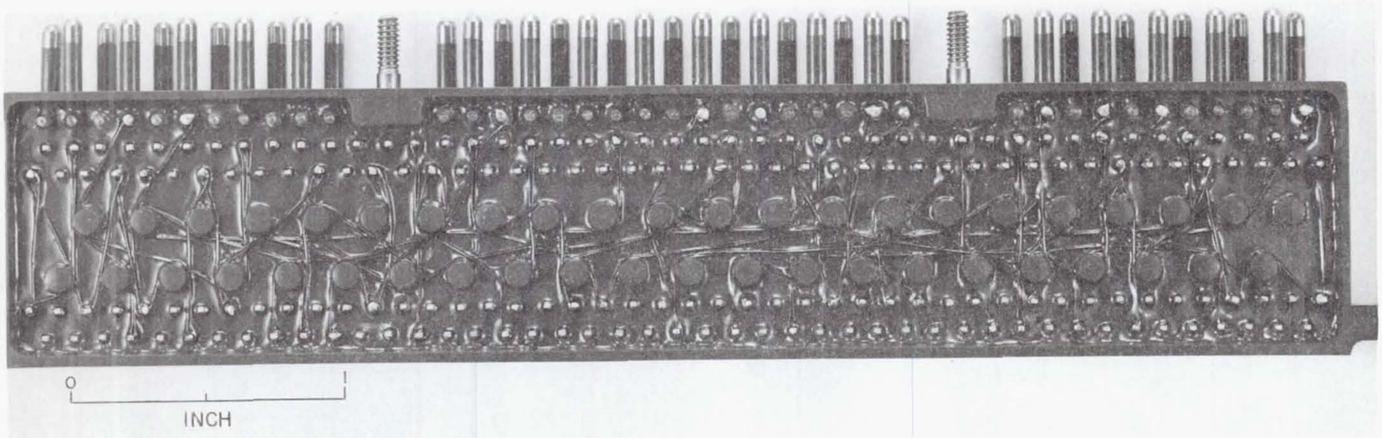


Fig. 7a. Integrated circuit - module intraconnect wiring

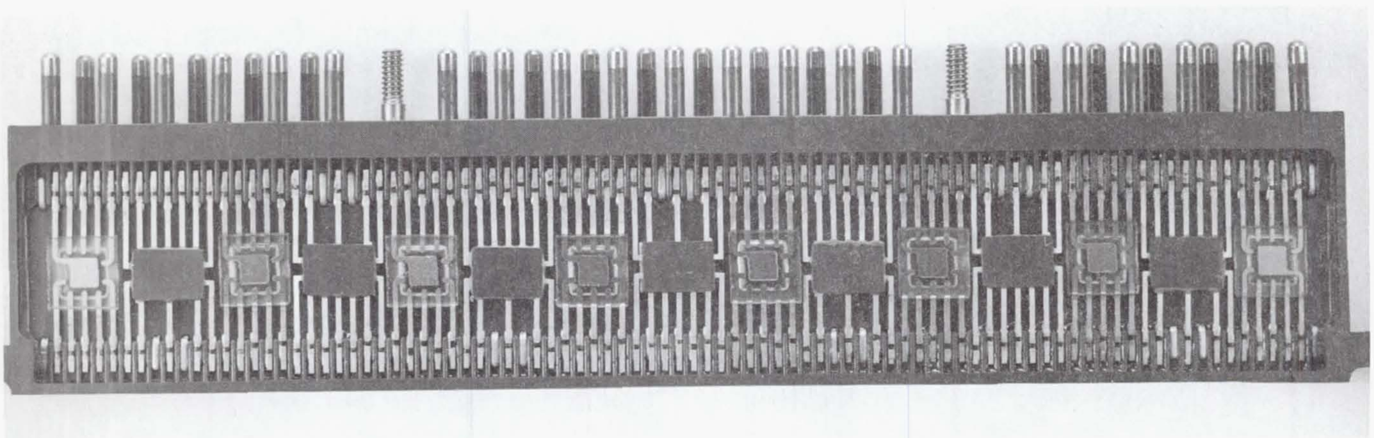


Fig. 7b. Integrated circuit - module with flat packs in place

The intraconnection of the flat pack integrated circuits ribbon leads to the stick module is done by use of a gold braze to meet the requirements of high reliability and repairability (Fig. 2). Repair of the welded, or brazed, joint is easily done by use of a wedge shaped tool that progressively cuts through the gold interface and removes the Kovar lead. The Monel terminal is then resurfaced to remove the residual gold and Kovar before rewelding a new lead in place.

Minimum design and fabrication time requirements are inherent in the present stick module concept. No accurate artwork is required at any level of assembly. All module intraconnection instructions are in the form of fixed routing rules and wire lists; the same is true for the assembly level interconnections of modules and external connectors.

The module interconnections are made by use of conventional Teflon insulated jumper conductors that run in one dimension and are coplanar. Preplanning and assignment organize the arrangement of the interconnecting bifurcated terminals, which allows the simplification of the assembly level interconnection.

The total modular assembly is designed to withstand high levels of environmental stress, i.e., 25 g sine sweep 0 to 2kc, plus gaussian noise, 500 g shock, and sterilization temperatures. The design can be scaled up to meet future planetary hard landing requirements.

Additional tasks that will be engaged in FY 1966 will include:

1. Study and evaluate existing microelectronic packaging techniques, and develop advanced configurations. Included in the evaluation will be multiple chip flat packs, flip-chip configurations. Flat pack and "TO" case integrated circuit test and handling carriers will be evaluated for laboratory use.
2. Microbond welding interconnection techniques will be studied and evaluated, and development work will be initiated to increase the reliability of this weak link in microelectronics device intraconnection.

MODULAR WELDED PACKAGING ADVANCED DEVELOPMENT (FY 1966 NASA Work Unit 186-68-10-09. JPL 384-66601-2-3570)

The welded matrix modular interconnect concept originated in the desire to provide a design technique to interconnect welded modules with a welding process (rather than soldering) and yet provide a module replacement capability without degradation of hardware as may occur in an etched circuit board with soldered connections. The matrix provides an interconnect assembly with all conductors in defined locations and thus offers a benefit as compared to a wire harness interconnect scheme.

Figure 8a shows the welded matrix modular packaging configuration in its present state of development at JPL. Each welded module lead is insulated from the magnesium chassis and interconnect matrix conductors by use of a plastic insulator. After fabrication, the welded matrix is cast in place with an epoxy resin system into the magnesium chassis to form a structurally integrated assembly. The welded modules are bonded in place, with a viscoelastic adhesive to provide additional assembly stiffness and to provide structural damping. The module leads are interconnected to the external matrix conductors by use of welded straps as shown in Fig. 8b.

The objectives of this task are to design and develop the best mechanically integrated nonmagnetic welded matrix configuration for Voyager based on the recently developed gamma ray spectrometer pulse-height analyzer welded matrix design, and to complete a detailed thermal study of welded cordwood modular assemblies.

The mechanical prototype pulse-height analyzer decoder subassembly is complete, and environmental testing has started. This configuration has been tested at levels up to 50 g rms 0-peak sine sweep 20 to 2kc with no damage or degradation; the transmissibility at the fundamental resonant frequency is extremely low (1.5) because of the viscoelastic damping incorporated into the design. The electrical prototype has been completed.

A typical example of flight type hardware with an interconnection density considerably greater than the pulse height analyzer decoder has been selected for the second design and fabrication exercise. A portion of the Mariner C data automation system required approximately twice the module interconnection density as previously considered in this development effort. Although the techniques of assembly remained the same, more effort was required in the detail design, because of the need to control tolerances to tighter limits to ensure the same ease of fabrication as previously experienced. Figure 9 shows a data automation system welded matrix before encapsulation.

The conductor material selection draws on the efforts of the electronic packaging advanced development task and now consists of a 0.010 X 0.030 cupro-nickel alloy (11% nickel), which provides a very satisfactory welding process to the riser or external connections that are gold-plated, oxygen free copper.

The degree of complexity of the welded wire matrix interconnections required four layers of conductors that did not prove to be a handicap in the assembly phases.

The fabrication to date has proceeded through the assembly and welding of the conductors and no difficulties arose in this phase of assembly. The embedment of the conductor matrix is also expected to yield no difficulties although the greatest difference between the previous pulse-height analyzer matrix and the present data automation system matrix lies in the techniques of mold sealing for the embedment process.

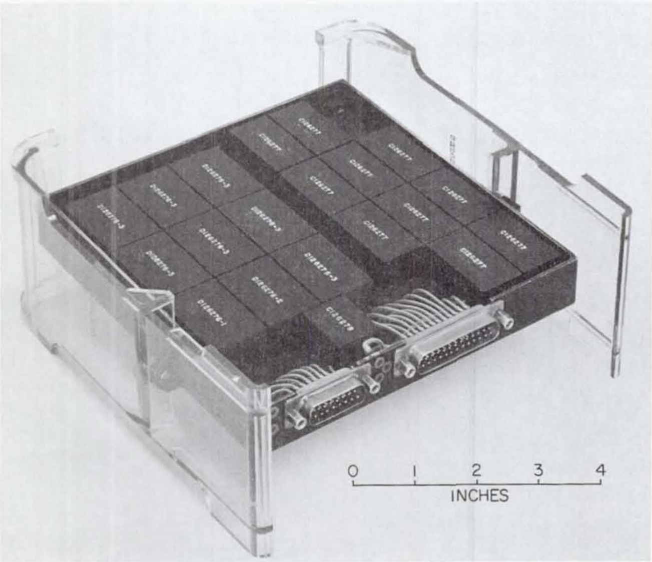


Fig. 8a. Welded prototype (PHA) decoder subassembly - modular matrix

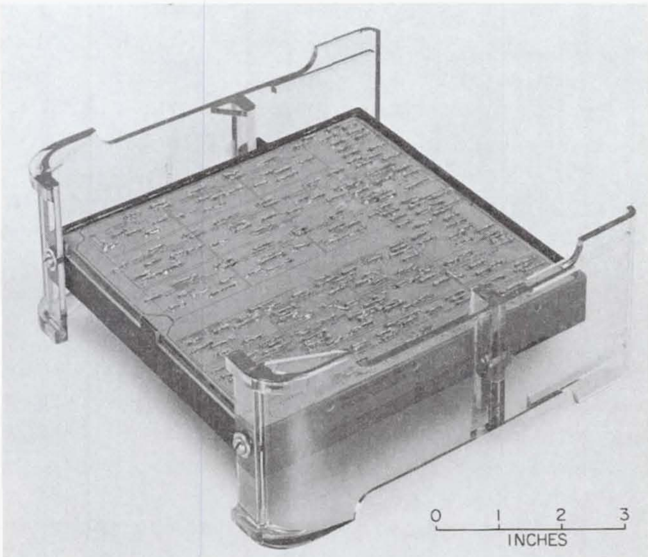


Fig. 8b. Welded prototype (PHA) decoder assembly - with module leads interconnected to external matrix conductors

In FY 1966, the welded matrix electronic packaging concept will be developed further for future spacecraft system applications, and the following tasks will be engaged:

1. Study the effects of varying geometry and the degree of structural integration and damping on dynamic characteristics of the subassembly.

2. Continue nonmagnetic conductor material and size study for a better joining process (independent of the electronic packaging advanced development, nonmagnetic interconnect task).

3. Develop better welded module attachment techniques.

4. Attempt to develop matrix configuration with reduced numbers of required interconnections.

5. Develop better welded module embedment techniques.

6. Thermal test modules have been fabricated with integral thermocouples that will be used to obtain detailed thermal characteristics. The thermocouple junctions are attached to resistor bodies within each modular embedment. Thermal profiles for typical modules will be obtained for all predictable conditions of component heat dissipation requirements.

7. Welded matrices and modules will be fabricated to further develop and qualify this configuration to ensure that physical integrity is reliably maintained under environmental stress.

The results of this development effort to be completed in FY 1966 will be reflected in Voyager design and process specifications.

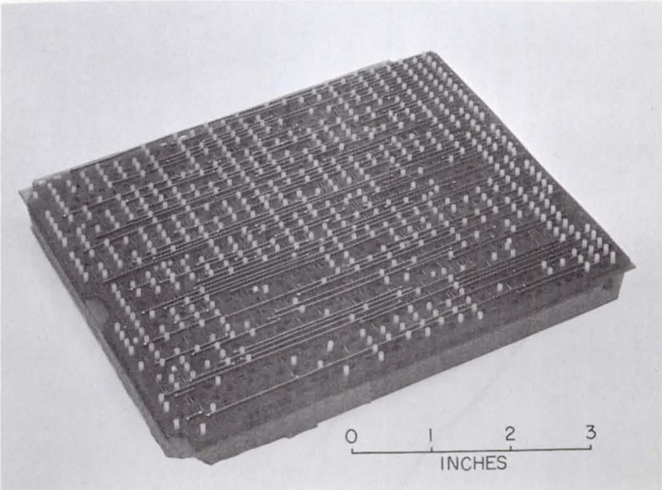


Fig. 9. Welded wire matrix before encapsulation

Page Intentionally Left Blank

TRACKING AND DATA ACQUISITION (125-22)

PLANETARY PROPAGATION
NASA Work Unit 125-22-01-01
JPL 325-20201-2-3362

No progress was made because of the lack of personnel to assign to this task. One engineer has been assigned half-time to this work unit for FY 1966 and is now available.

The FY 1966 program will be directed toward developing analytical descriptions of radio propagation from antennas landed on extraterrestrial bodies. Cases to be covered include multipath from the planetary surface, effect of complete or partial burial on antenna parameters, and communication problems associated with obstructions.

Page Intentionally Left Blank

QUANTUM ELECTRONICS RESEARCH
NASA Work Unit 125-22-02-01
JPL 325-20101-1-3335

FEASIBILITY OF OPTICAL SPACE COMMUNICATIONS AND TRACKING

The revision of estimates of spacecraft to Earth optical communications is continuing. A possible advantage over S-band occurs at a wavelength of 10 μ, but only under a restrictive set of assumptions. The data rate would have to be variable, because the system capability would depend strongly on weather, not only clouds, but also atmospheric turbulence that affects the coherence of the signal. This might apply to some future mission that transmits routine television from a planet, as opposed to pictures that are all taken at a critical time. We shall not assume that a spacecraft can store power to take best advantage of good conditions.

Table 1 shows a comparison, in decibels, for three choices of wavelength. The decibels are only relative, i.e., not normalized to any requirements or standard system. Thirteen cm represents S-band, 10μ represents the longest wavelength infrared window at which coherent receivers may be barely feasible, 0.84μ represents the very compact and efficient galium arsenide laser.

The figure of 36 db spacecraft antenna gain does not represent any mission. Rather, it is an attempt to keep the wavelength comparison fair by assuming an antenna erection and pointing problem with difficulty comparable to the laser beam pointing problem. The 2.1 ft transmitter aperture at 10μ would produce a beam about 3.5 arc-sec wide. For comparison, the Earth subtends about 9 arc-sec at 2 AU. The spacecraft antenna pointing system should be able to divide the Earth's disk into the required number of resolution elements (about 10) by using the same telescope for both data transmission and Earth tracking. A reference point can be derived by dividing the visible disk or crescent into quadrants with opposing ones containing equal light intensity. The offset from this reference would have to be updated.

The figure -10 db for the affect of atmosphere on 10μ communication is conservative. It represents angular resolution of about 14 arc-sec, poor conditions at high elevation angles, or average conditions at some low elevation depending on the tracking site. If data rates are fully flexible, 10 times as much data could be received at favorable times, which would strongly weight the average rate toward the higher values.

The validity of the table is limited by the fourth item, number of dishes. Here the limits are economic. These numbers merely represent telescope cost ratios. We have not done enough system studies to include electronic and operating costs, which in practice are the major ones. So far we have been concerned with the choice of a promising wavelength, which strongly influences system considerations. The tentative choice of 10μ results from very recent improvements in gas laser design.

Three problem areas raised by optical communications studies are as follows:

1. Can gas lasers be made efficient in the near infrared where photon counters are effective? A study contract for $69,600 with

Table 1. Comparison of wavelength, db

Item	Wavelength		
	13 cm	10 μ	0.84 μ
Transmitter power conversion efficiency	- 7	-21 ± 3	2.5%, -16
Transmitter spacecraft antenna G.	10 1/2 ft, 36	2.1 ft, 104	17 cm, 107
Receiver area, 1 dish	210 ft, 46.4	100 in., 18.4	107 in. 19
Number of dishes	1 dish, 0	7 (?) dishes, 8.5 ± 3	4 to 16 dishes, 9 ± 3
Bits of information/ Joule received.	$(k25°)^{-1}$, 214.6	$(10\mu/hc)1/2$, 194	$(0.84\mu/hc)/400$, 160
Atmosphere, clouds, optics	0	-10-1-1 = 12 ± 5	-4-1.3 = -8
Bonus for spacecraft weight saving (could be used for extra solar panels)			4 ± 1
Total	290	292 ± 7	275 ± 4
Qualitative advantage			
Less severe pointing problem	X		
All weather operation	X		
No spacecraft antenna erection		X	X
Phase of carrier wave under control		X	X
Compact and solid state			X
No concern for multipactor or gas discharge losses in spacecraft		X	X

Hughes Aircraft was aimed at this question. The work was completed in April 1965 without attaining its primary goal of greater laser efficiency by injection of mono-energetic electrons. However, the contract produces a relatively high power laser at 9μ that we shall use in problem 2. It also produced two papers, one announcing a new laser oscillation, the other giving extensive performance data of value to researchers. Details are available in the form of Final Report, JPL Contract No. 950803, "Investigation of the DC-Excited Xenon Laser," April 1965.

2. How much signal degradation in the 8 to 13μ window is caused by atmospheric turbulence? We have started a project to examine 9μ interference fringes after the two interfering beams have traversed different atmospheric paths. Except for Hughes 9μ laser, this project is still in the procurement stage.

3. What problems and costs are encountered in attempts to use very large optical apertures or multiple telescopes? We are negotiating a study contract to examine the optical analog of the Arecibo spherical reflector antenna with segmented primary optics.

FAR INFRARED MASER

At its present stage, the optical communications studies use less than half the personnel and in-house facilities of the Quantum Electronics group. The rest are engaged in a basic research problem to design a novel type of maser; which, if successful, would be the first to operate on a molecular transition in the pure rotation spectrum. The detailed theory is described in a paper scheduled for publication in the September 1965 edition of the Journal of Applied Physics "Proposed Gas Maser Pumping Scheme for the Far Infrared" by W. H. Wells. Briefly, a molecular beam of HF interacts by distant collisions with a cold (80°K) rarified (10^{-5} torr) atmosphere of HCl. Because of resonances in the rotational spectra of the two molecules, the HCl is expected to cool the J = 2 and J = 1 rotational energy levels of HF much more effectively than the J = 3. This should leave a population inversion in the $J = 3 \rightarrow 2$ radiative transition of HF, which is expected to oscillate where the beam enters an appropriate resonator. We expect to detect oscillation indirectly by analyzing the rotational state of the molecular beam by electrostatic deflection as it passes out of the resonator. In this way we can obtain diagnostic data and molecular interaction cross-sections whether or not the oscillation occurs.

The molecular beam chamber and associated cryogenic and vacuum equipment are completed. With the aid of a mass spectrometer, we have studied the problem of detecting the HF beam despite its chemical activity. We are trading in the spectrometer for a model equipped with an electron multiplier for greater sensitivity. The electrostatic deflector has been designed and built. Nozzle and chemical problems are not yet solved. An optical resonator design for intercepting the molecular beam resulted in a computer program to find the normal modes of a Fabry-Perot resonator with tilted plane mirrors. The integral eigenvalue equation proved interesting in its own right. The program is almost complete, and all essential results were reported in SPS Vol. IV, issues 37-29, pp. 200-205; SPS 37-30, p 231; and SPS 37-33.

Page Intentionally Left Blank

LARGE APERTURE ANTENNA STUDY
NASA Work Unit 125-22-02-02
JPL 325-20401-2-3362

ANALYTICAL STUDY

The object of the analytical portion of this study is to obtain design parameters for maximizing the gain to weight ratio of erectile antennas and to calculate the gain of large aperture antennas.

To perform the analytical study of large aperture antennas, a computer program is to be developed to calculate the secondary patterns of various antenna configurations.

Due to demands from the Mariner and Surveyor flight programs, progress in this study has been limited to organizing the computer program and deriving surface equations to be used as program inputs.

After investigating various techniques, the surface current method as outlined in Silver[1], Section 5.7, has been selected as the most applicable technique to use in analytically evaluating the gain of large aperture antennas for spacecraft. The surface current gain analysis method is to form the hub of a computer program to calculate gain as shown in Fig. 1.

The program will be sequentially developed to include as input data not only analytical or experimental feed amplitude patterns, but also feed phase patterns, and feed polarization patterns. Simultaneously with the addition of each of the illuminating feed characteristics, the program output will be expanded to yield similar information on the large aperture antenna pattern. The experimental data describing the feed characteristics will come from tapes generated by using the digital antenna pattern recorder.

The program is planned to be general enough to allow for calculating the gain of regular surfaces of revolution and segmented erectile reflector surfaces.

The surface equations for an erectile antenna consisting of flexible reflecting material pulled uniformly between purely radial ribs have been derived. This particular class of reflector surfaces formed with radial, two dimensional, curved ribs consists of gores that are developable surfaces. The developable surface is easy to fabricate and may lend itself to simple erection schemes.

Formal writing of the gain calculating program has been delayed pending the completion of a general equation that can describe an erectile surface in terms of a three dimensional rib curve.

To facilitate the gain calculations, use of complex vectors has been investigated to describe the feed and secondary pattern polarization. In addition, the feasibility of using the VECTRAN computer routine to handle the required vector operations is being investigated.

---

[1] S. Silver, Microwave Antenna Theory and Design, McGraw-Hill, New York, 1949.

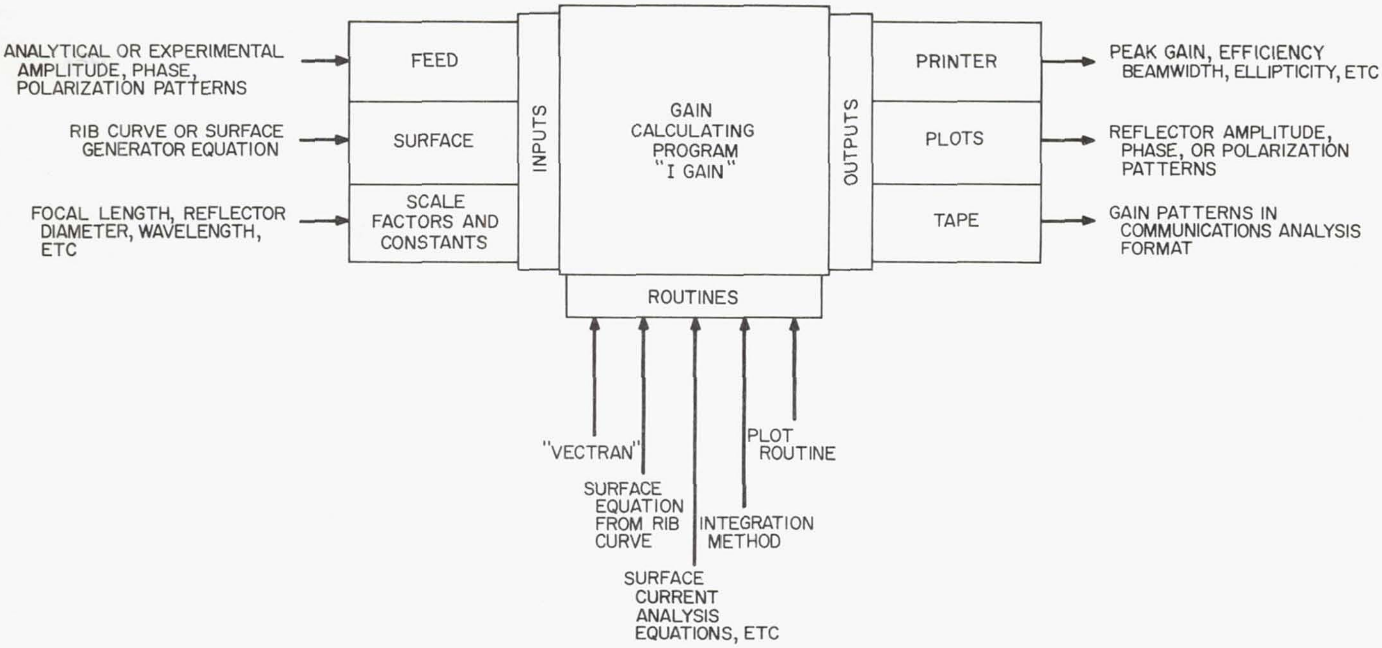


Fig. 1. Block diagram of the computer program to calculate large aperture antenna gain

A selection of outputs from the program is planned to allow the program to be used for parameter betterment studies or to generate theoretical secondary patterns. The theoretical secondary patterns would be used in advanced project studies that require large aperture antennas for communications.

In support of the analytical portion of this study the author is planning to attend the Ohio State University short course on "Antenna and Scattering Theory: Recent Advances," from August 9 to 20, 1965.

EXPERIMENTAL STUDIES

In support of the analytical study, development of an experimental program is underway. The experimental data will be used to check the accuracy of the analytical results and to generate input data for the computer program.

One S-band antenna feed is planned to be used throughout the early portion of this study. The feed will be used to illuminate medium diameter (e. g., 3 ft) models of erectile reflector surfaces. A procurement requisition for a feed used with a 9-ft diameter erectile antenna has been initiated. This feed can be readily adapted for the short focal length required by the erectile reflector models.

To record phase patterns, the serrodyne technique will be used. With the aid of an investigation of existing serrodyne systems, an S-band serrodyne system was designed. Procurement requisitions for the equipment, totaling $20, 790, have been initiated. Delivery has been requested for mid August 1965. Construction should be completed by October 1965.

To obtain polarization patterns, a dual-circularly polarized antenna range illuminator will be designed in FY 1966. However, in order to record polarization patterns with the digital antenna pattern recorder, additional signal processing equipment will be required to make the illuminator output compatible with the recorder input.

Experimental measurements are now scheduled to begin in mid FY 1966 as the next six months of this study will be primarily concerned with writing and checking the computer program.

ERECTILE ANTENNA DEVELOPMENT

Goodyear Aerospace Corporation has been working on a Phase II contract to make required modifications to the erectile antenna that they had built for JPL. The contract was awarded on June 18, 1964 for $110, 000. Part I of their contract was a study to review all the techniques that might be used to correct certain problem areas in the antenna design and to select the best approaches. This part was completed the first of this calendar yr. Part II started the first of this calendar yr and covers the hardware design and fabrication to incorporate the selected modifications into the original erectile antenna. Part II is scheduled to last until the end of August. Part III, contractor evaluation of the antenna, is to begin in September and last until October 15th, the scheduled contract completion date.

The most significant effort in part II has included the re-design of the folding ribs from constant section tubes to tapered tubes to reduce weight because the large sections at the end of the tubes do not add appreciably to the tube overall stiffness and strength. A new system of locks was developed to hold the ribs in the open position that would allow more precise location of the ribs and hence a more accurate reflecting surface. A technique utilizing tie down wires has been designed to improve the contour accuracy of the antenna. A new material (tin-plated copper) has been selected for the surface screen. Modifications are estimated to be approximately 2/3 complete.

Work to be completed on part II includes installation of the tubes on the hubs, adding the new surface mesh or screen, adding the tie downs and adjusting the shape of the antenna.

Part III will include antenna pattern measurements, contour accuracy measurements as a function of degree of antenna deployment, and environmental measurements.

A procurement has been started to purchase state-of-the-art erectile techniques that industry may have independently developed to compare with the Goodyear design. The purpose will be to establish the overall state-of-the-art of erectile antennas. $35, 000 has been set aside for this purpose.

Page Intentionally Left Blank

MULTIPACTING AND IONIZATION BREAKDOWN STUDIES
NASA Work Unit 125-22-02-03
JPL 325-20501-2-3362

ANALYTICAL STUDY

Similarity relations have been used in various branches of physics and engineering. In deriving these relations, a complex analysis very often is avoided and much pertinent information is gained through a minimum of effort. In view of the extremely complicated and difficult analysis required for multipacting breakdown geometries other than parallel plates, such relations would undoubtedly prove valuable.

Since the phase relationship between the electron and the electric and magnetic fields is the prime controlling factor of the multipacting mechanism, similarity conditions in this vein were sought. Therefore, scaling techniques were applied to the equation of motion for an electron in electric and magnetic fields along with its boundary conditions and a similarity principle for multipacting resulted. The results obtained are briefly described below.

1. When applied to parallel plates geometry, the similarity principle rendered a justification and a physical meaning to a very criticizable assumption made by previous workers in successfully predicting their multipacting regions.

2. With the similarity principle as a guide, an improved and more satisfactory analysis of one-sided multipacting in parallel plates geometry was carried out.

3. An analysis for multipacting in parallel plates geometry in the presence of a steady transverse magnetic field was made. It was shown that in the presence of a small steady magnetic field, the breakdown curve shifts to higher breakdown voltages and lower cutoff frequencies. When the magnetic field is increased such that the cyclotron frequency approaches the applied frequency, one-sided multipacting is possible. The similarity relations for this one-sided case have been derived.

4. For coaxial geometries, the case where the b/a ratio is constant (a and b are the inner and outer radii of the coaxial electrodes respectively) was studied. This is particularly useful since in a transmission line this means that the characteristic impedance is held constant. For the phase controlled boundaries, it was found that $v_{RF} \sim (fa)^2$, where v_{RF} is the magnitude of the RF voltage and f is the frequency. With a dc voltage v_{dc} introduced, the additional relationship $v_{dc} \sim (fa)^2$ holds.

5. For a discone antenna biased by a dc voltage, v_{RF}/v_{dc} is a constant for the phase-controlled boundary of the multipacting region.

A paper covering the similarity principle and its applications is in draft form and will be submitted for outside publication. It is also planned to present a paper on

this material and any additional findings from our other studies at the Eighteenth Gaseous Electronics Conference sponsored by the American Physical Society to be held in Minneapolis, Minnesota, October 20-22, 1965.

A computer program has been written to numerically integrate the normalized differential equation describing the electron motion between coaxial electrodes. This program was written for two purposes. Firstly, the solutions would give us typical electron trajectories and allow some conclusions to be made as to the coaxial multipacting mechanism. Secondly, it was felt that some correlation existed between the parallel plates geometry and the coaxial cases especially where b/a is large. The solutions would permit comparison and give an indication as to the b/a range in which this correlation holds.

EXPERIMENTAL STUDY

Before a large scale testing program is undertaken with typical hardware components, some measure of the pressure levels within the components needs to be secured. The reason for this is that there are indications that the pressure levels within the components could be many times higher than ambient pressure. Multipacting occurs at low pressures ($\sim 10^{-6}$ mm Hg) while ionization at higher pressures (~ 1 mm Hg). Thus, even though the components are in a low vacuum, ionization rather than multipacting could be the dominant mechanism. It is also suspected that while multipacting could be the starting mechanism, the pressure levels rise many times due to outgassing and heating and ionization breakdown takes over. Pressure monitoring tests employing a strain gage and an alphatron gage have therefore been set up and a series of pressure tests are presently being run. These tests do not involve any breakdown experiments.

From the results of our pressure monitoring tests, effort will be made to establish an experimental setup in which pressure may be regulated and monitored while testing coaxial components for multipacting and ionization breakdown. Actual breakdown testing will start when the necessary high power equipment becomes available.

When the breakdown facility is completed, breakdown experiments with antennas are also planned. Of particular interest will be the lower frequencies (100 - 500 Mc) where multipacting is more likely.

There are two distinct advantages in gathering multipacting data at frequencies below 100 Mc. Firstly, at these frequencies dimensions of electrodes are larger. Secondly, open electrodes are employed such that sufficiently low pressure levels between the electrodes is assured. A procurement requisition in the amount of \$6,000 has been initiated for a contractor to perform such experiments with typical coaxial electrodes. These experiments will involve both one-sided and two-sided multipacting. The data gathered will serve to support our analytical studies and can be extended to microwave frequencies through our similarity principle. It is also hoped that with the data obtained a more complete analysis can be made with the aid of our computer study results.

The consultant contract with Dr. Akira Ishimaru ends June 30, 1965. He has been assisting on the analytical studies for multipacting and the total amount of his contract is \$3,480. During the last period, a contractor technician was hired to support our experimental study.

Procurement of equipment necessary for our breakdown testing is underway and expected to be completed by December 1965. The contractor for our 1-kw VHF source has defaulted and a new procurement has been initiated.

For the breakdown facility, only the screen room and plastic shell remain to be procured. Bids have been received for the breakdown facility building, and we are in the process of awarding the contract. It is expected that the complete facility will be operational by January 1966.

Page Intentionally Left Blank

DATA HANDLING AND PROCESSING (125-23)

GSE DEVELOPMENT FOR ADVANCED SPACECRAFT
NASA Work Unit 125-23-01-01
JPL 325-31501-2-3430

The evaluation of circuit testing techniques to detect incipient failures continues. The objectives of the ground support equipment (GSE) development task are to devise more comprehensive GSE testing techniques and other spacecraft tests which will result in a more reliably operating spacecraft. The following testing techniques are currently being investigated: (1) margin test techniques for GSE and spacecraft equipment, (2) RF noise spectrums, and (3) infrared measurements of the various circuits.

A digital test circuit which cycles through a short operational routine is being used for evaluating the various testing techniques. Measurements are also being made on several spacecraft central computer and sequencer (CC&S) subsystems.

STATUS

A status report of this study was published in SPS 37-32, Vol. IV, pp. 52-57. Photos show the various test set ups used to take RF noise measurements. Graphs show typical voltage margin shmoo diagrams for the digital test system and for an individual circuit card. The RF noise spectra of the digital test system and of a circuit card are shown by graphs also.

Voltage Margin Measurements

Voltage margin measurements of the full digital test system were completed the first part of the third quarter. The measurements were obtained by varying the +12- and the -12-v supplies from the nominal voltages until a partial system failure resulted. The power supply voltages were varied further until a second system failure resulted. These 6 different partial failure conditions are located in the 6 areas indicated on the shmoo diagram in the SPS. The use of partial failure information is expected to reduce somewhat the limitation of masking.

Masking effects become evident considering that the malfunction of the weakest link in the system determines but one margin measurement at which the system fails. It may well be that another component is drifting much faster and will be the one to cause system failure, but at the moment its margin characteristic is just beyond the one causing the present failure. The digital test system did not fail completely at the first critical voltage value so it was possible to continue to vary the voltage until other failure indications were observed. We expect to obtain additional trend information by using the data where the system operates erratically.

Circuit Noise Measurement

A double layer copper screened box was constructed to hold a circuit card and the test fixture while obtaining the noise measurements. The RF noise spectra for each circuit card were taken; (1) with power on but the circuit not operating, and

(2) with power on and the circuit in operation. The measurements were made on the +12- and -12-v power lines at the card.

Noise spectra measurements were taken on 30 of the 31 circuit cards. A noise spectrum was taken for each of the different circuit operations possible on each card. These spectra have been plotted on graph paper for reference in future measurements.

Noise spectra measurements were also taken on two Ranger CC&S's operating with the GSE. The equipment and cables were placed in a large RF shielded room to eliminate interference. The CC&S's measured were early models that had been used and modified many times. Each equipment showed a characteristic RF signature. RF noise measurements will be made on flight quality equipment for comparison as it becomes available.

There has not been an indication as yet that the noise of a defective component will be easily recognized by the present measurements, although others have reported some success in using RF noise to locate defective components in control systems.

Infrared Measurements

Very few infrared measurements have been taken of circuit cards since the last report. Measurements had been postponed so they might be taken with the same camera when a new infrared camera was purchased last fall. The 4-to-1 improvement in spatial resolution over the previous camera was obtained at the expense of temperature sensitivity. The resultant pictures now at circuit board temperatures are very noisy. Detailed calibration curves were recently completed and sent to the manufacturer. The manufacturer reports that the temperature sensitivity of the camera has apparently decreased by a factor of 3 or 4. Present plans are to have the camera repaired and modified for improved temperature sensitivity.

PLANNED ACTIVITIES

The evaluation of the circuit testing techniques to detect incipient failures will continue in the next FY. The infrared camera will be repaired or modified so reference pictures can be made of all circuit cards.

With the completion of reference margin, RF noise, and infrared data the accelerated life test will be made on the digital test system. Measurements will be made periodically in each area to determine trends. The correlation in test data will be determined.

Voltage margin, RF noise, and infrared measurements will be made on spacecraft subsystems. RF noise spectra will be taken on Ranger flight-quality CC&S equipment when this equipment is released from the Ranger program but before it starts a scheduled life test. Infrared data will be taken when the camera is returned after repair. This data will continue to be taken during the life test for trend analysis.

DIGITAL VIDEO PROCESSING
NASA Work Unit 125-23-02-01
JPL 325-30101-X-3184

DIGITAL VIDEO PROCESSING - CONTRACT: SYSTEMS PROGRAMMING CORPORATION

Due to a severe budget cut at the end of the first quarter, digital program development has not been supported by this task. During this report period, advancement of the programming and processing of the Ranger pictures have, however, been supported by the Ranger program. It is anticipated that with the procurement of a small computer, this task will support some of the programming required during the next FY. It is planned that the flight projects will support the required flight peculiar programming.

DIGITAL COMPUTER

It has been found possible, in conjunction with support from the Ranger program to fund the purchase of a small general-purpose computer. This is the computer previously planned under this work unit, but which has been deferred up to now for budgetary reasons. As of the end of this reporting period, funds have been allocated, and the computer specifications being defined. This is to be a machine of the DDP 224 or SDS 930 class, with 8-K memory and high speed tape decks.

VIDEO FILM CONVERTER (VFC) - CONTRACT: LINK DIVISION, GENERAL PRECISION, INC. (FROM FY 1964 TASK 125-23-01-01, DIGITAL VIDEO SYSTEM)

The VFC is essentially complete, in accordance with the originally specified capabilities. Due to its continued heavy use in supporting flight programs during this reporting period, it has not been possible to release the machine for the planned upgrading. As a result, although some of the engineering for the upgrading has been accomplished, no hardware modifications have been made. It is now planned that after the use of the VFC in support of Mariner encounter, it can be released for the planned upgrading. The FY 1964 funds have been carried over for this purpose.

KODAK CRT RECORDING FILM AND BIMAT PROCESSING

Kodak has now completed the development of the S0337 CRT recording film and has announced it publicly, together with associated bimat processing. This film and the bimat processing were used to produce the quick, high quality positives and negatives for the Ranger IX mission. An entry has been prepared and submitted for inclusion in SPS 37-33, Volume IV. This includes a discussion of the Ranger support activities, characteristic curves for the film and processing and a discussion of the processor used.

BIMAT PROCESSOR - CONTRACT: MARK SYSTEMS, INC. (FROM FY 1964, TASK 125-23-02-01, DIGITAL VIDEO SYSTEM)

This processor has been received, and was used in support of the Ranger IX mission. It is capable of processing up to 100-ft of either 35 or 70 mm film with bimat. A description and pictures are included in the SPS entry discussed above.

SPACECRAFT TELEVISION GROUND DATA HANDLING SYSTEM (SCTV-GDHS)- CONTRACT: LINK DIVISION, GENERAL PRECISION

Personnel assigned to the digital video system task are contributing in a consulting category to the technical direction of the SCTV-GDHS. Thus, much knowledge derived in the digital video system activity is being applied to direct flight support.

SPLIT FREQUENCY RECORDING

It has now been determined that because of the characteristics of presently available tape recorders, an intolerable amount of picture degradation will occur upon attempt to record the video at slow tape speed. Since this slow tape speed was the purpose of using the split frequency recording, this item has now been dropped.

FOCUS MEASURING DEVICE

This device, which will measure the degree of focus of the cathode ray tube in the film recorder, will be brought to the laboratory during the month of July for checkout. We are presently considering the LogEtronics Focatron for this purpose.

CONTRACT STUDY - GAMMA CONTROLLED FILM PROCESSING

Due to lack of available manpower, this study was not pursued during this FY. The need for this processing has not decreased, however, and it is anticipated that we will start it during the next reporting period.

SPS ENTRIES

The lunar television image converter (TIC) has been defined as the aggregate of all the interconnected equipment involved in this task. It is described, together with a brief discussion of the digital video processing, in a Volume IV SPS entry in March 1965. This discussion also includes the use of this equipment in the processing of Ranger pictures.

SYMPOSIA

F. C. Billingsley presented a paper at the Society of Photographic Instrumentation Engineers (SPIE) Annual Seminar-in-Depth in April 1965. The title was Digital Video Processing at JPL. He has been invited to present essentially the same information at the SPIE annual convention in August 1965.

DATA COMPRESSION

This group has made available to the Lockheed Missiles and Space Corporation some of the Ranger VII pictures in digital form. LMSC is active in the data compression field, and is making available to us results of their processing on the Ranger data.

OPTICAL PROCESSING

Due primarily to lack of manpower, we have been unable to begin the study of optical video data processing techniques. It is desired that the study begin with the

analysis of a cathode ray tube recording system, and with the possibility of applying spatial frequency filtering to the video pictures. It will then be expanded to cover other coherent and incoherent light processing techniques. The sooner this work can begin, the greater will be its usefulness to the digital video processing activity. However, presently available manpower cannot be diverted to this task; addition of one engineer is required if this is to be accomplished.

Page Intentionally Left Blank

SLOW SCAN VIDEO DATA COMPRESSION AND MODULATION

NASA Work Unit 125-23-02-03

JPL 325-30301-2-3341

IN-HOUSE TV DATA COMPRESSION STUDIES

Computer Studies

The video data compression and modulation task deals with the effects of the noisy TV sensor and the noisy communications channel on the various data compression and synchronization techniques. The video modulation test console, shown in Fig. 1, provides the means of generating and reproducing slow scan TV signals. The test set-up block shown in Fig. 1 and detailed in Fig. 2, which is not an integral part of the slow scan test console, has the function of simulating:

1. Spacecraft TV data compression, synchronization, and signal processing functions.

2. Noisy communication channel.

3. Ground TV signal demodulation, decoding, synchronization and formatting of the TV signal for proper display by the slow scan monitor.

The current method of simulating various TV data compression and transmission systems is shown in Fig. 3. The digital format converter collects the digitized TV data and produces a 7094 IBM computer compatible magnetic tape. This magnetic tape is then translated to a Fortran program compatible tape by an existing computer program (called DADCO), then processed as shown in Fig. 3. The final result is a magnetic tape compatible with Section 318's Link photorecorder. Playback of this magnetic tape then results in TV pictures being placed on 35 mm film which is subsequently developed with a gamma of approximately 1.1.

Computer programs have been written for most of the processing functions shown in Fig. 3, but not all computer programs have been debugged. A few pictures have been produced by this method.

As can be seen from Fig. 3, this method requires a number of intermediate steps before the desired output tape can be generated. The turnaround time for this method is approximately 1 wk. The basic problem with this method is the inability of the computer programmer to change program parameters during one simulation experiment as he so desires.

By replacing the test setup with an on-line computer, a much more flexible and efficient simulation system can result. The following savings result: (1) new hardware need not be constructed each time a new simulation function is needed, (2) direct computer operator intervention can be done when it is determined that the particular parameters of the simulation experiment need to be modified, and (3) turnaround time is reduced to a minimum.

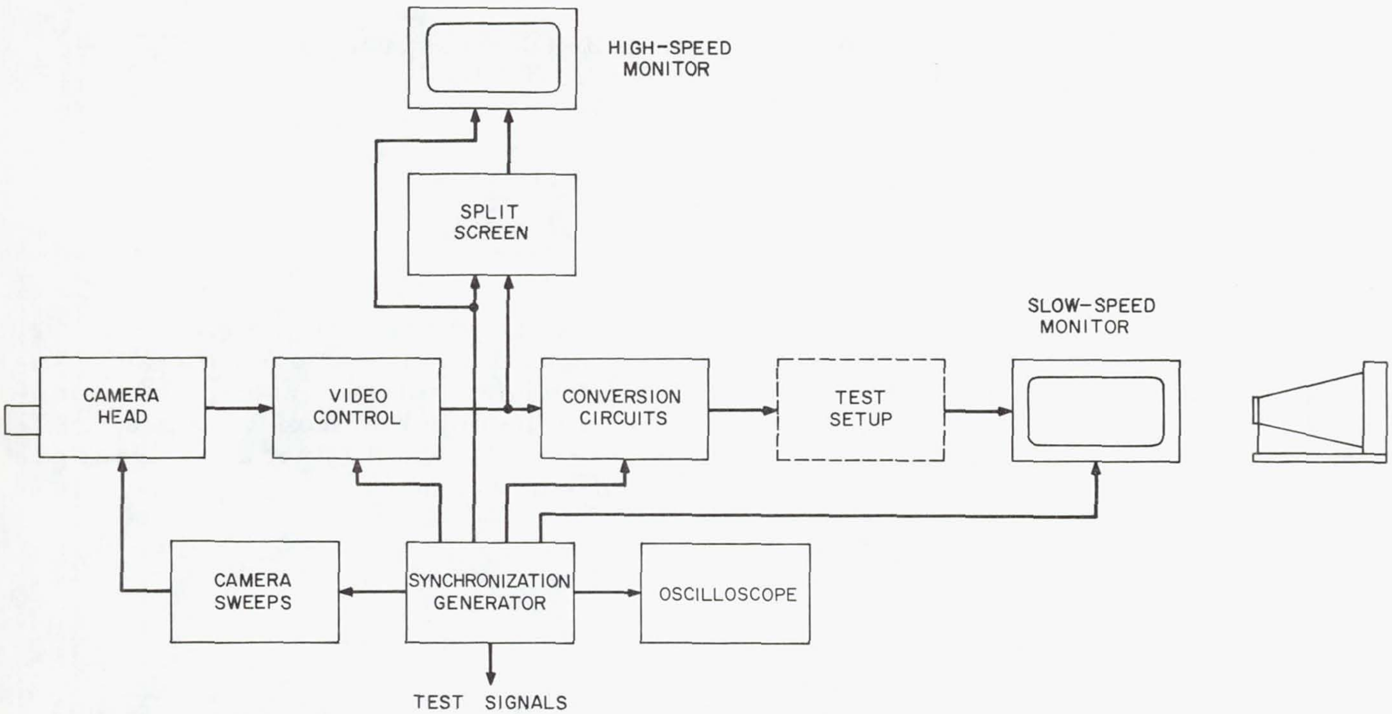


Fig. 1. Test console system block diagram

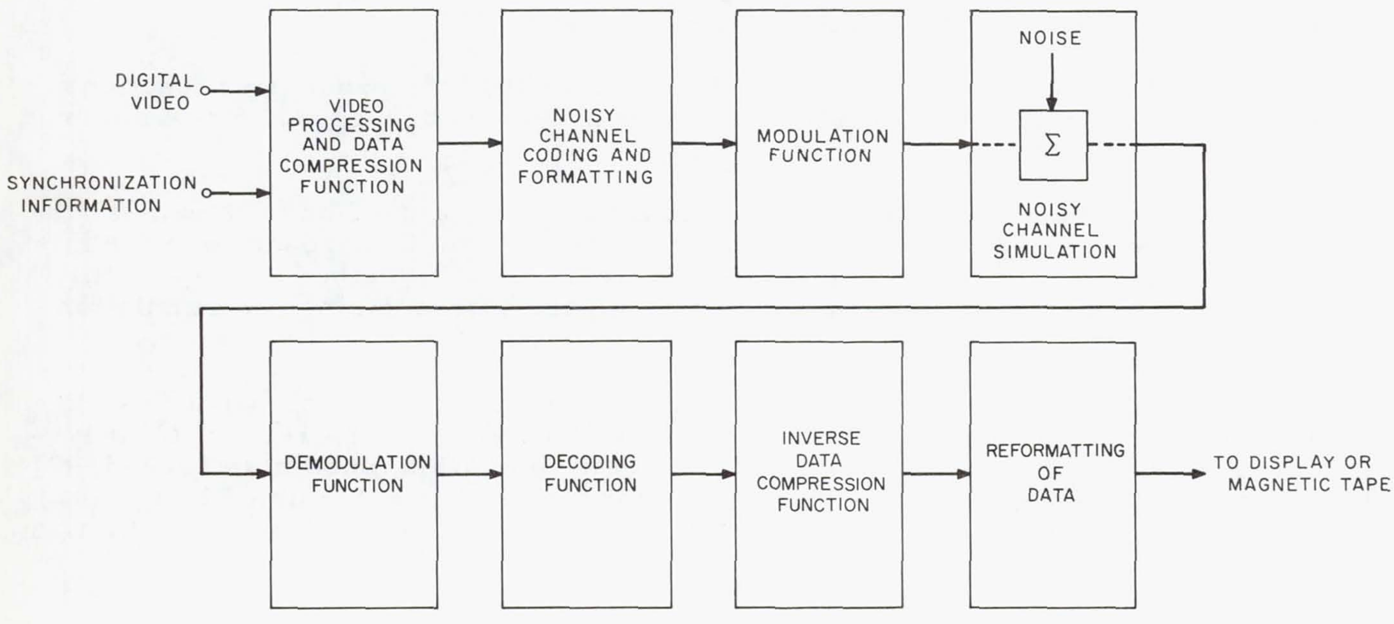


Fig. 2. Detailed test console system block diagram

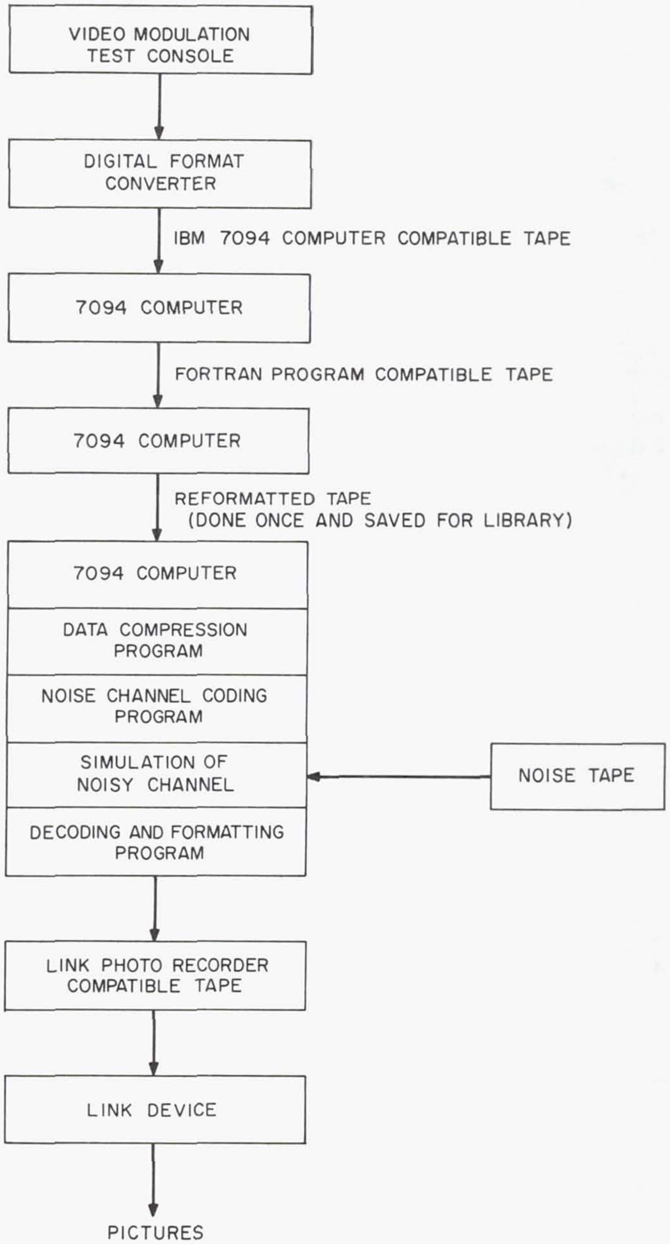


Fig. 3. Simulation of various TV data compression and transmission systems

All remaining procurement funds in this task were committed to contribute to the purchase of an SDS 930 computer which will be used to perform the function of simulating the TV compression system. The SDS 930 computer should be installed by September 1, 1965.

Figure 4 shows the proposed interface between the video modulation test console (VMTC) and the computer. The computer is controlled by the slow scan VMTC Data Generator.

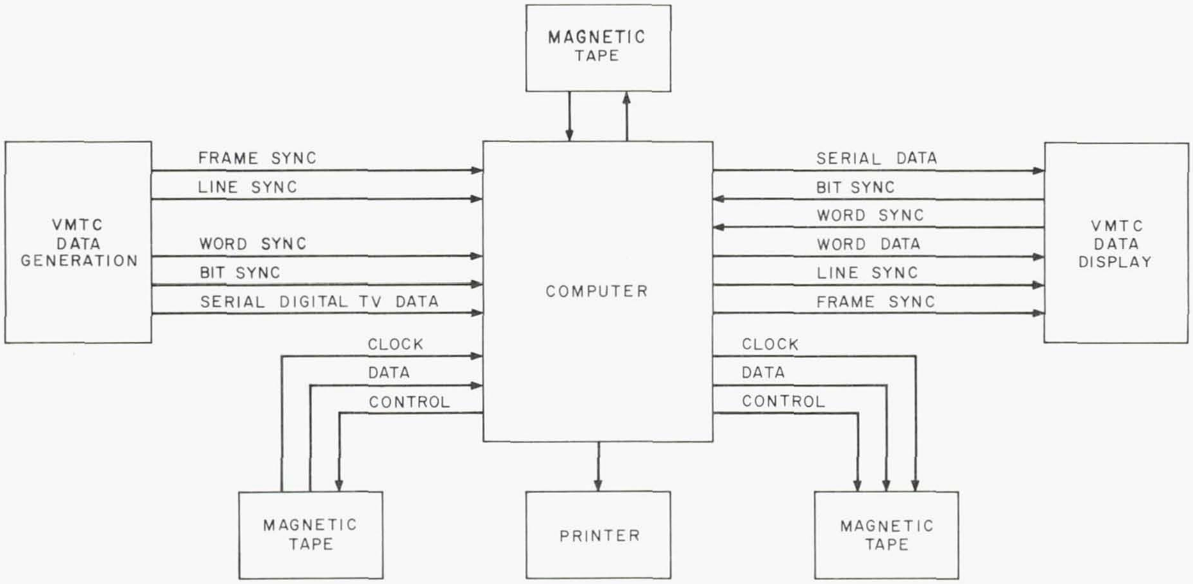


Fig. 4. Proposed interface between the video modulation test console and the computer

a. Inputs to Computer.

1) Synchronization signals - digital in nature.

2) Digital TV data - one to 10 bits/sample.

3) Magnetic tape - this would be used to input digitized Ranger pictures or Mariner pictures which are already in digital form.

b. Computer Functions.

1) Linear or nonlinear processing of the input TV samples simulating additional parameters of a spacecraft TV camera which are not included in the VMTC.

2) Simulate a spacecraft TV compression system including the synchronization function.

3) Coding of the compressed TV data for the noisy channel.

4) Simulation of the decoding of data output by the noisy channel.

5) Simulation of the noisy channel.

6) Simulation of the inverse function of TV data compression.

7) Simulation of the process of gaining synchronizing information.

8) Reformatting the TV data for proper display.

9) Outputting the TV data to the display devices or to magnetic tape.

c. Computer Outputs and Output Control Functions.

1) VMTC data display.

a) Frame sync from computer to control start of data display.

b) Word sync from VMTC - controls computer for data transmission.

c) Line sync from computer to control beginning of line in VMTC.

2) Magnetic Tape.

This tape would be used to reproduce high-quality photos on the Link photorecorder.

3) Scratch Tape Machine.

a) Used as internal machine buffer.

b) Output of program processing parameters.

Theoretical Studies

The effect of sensor noise on quantization accuracy in a digital TV system has been investigated and reported on in an internal JPL Technical Memo.

The relation of sampling frequency and analog-to-digital converter quantization to resolution in a digital TV system has been investigated and will be reported on at a later date.

A study has begun to determine the requirements of a data compression system for a Voyager class mission. The study includes TV data compression techniques, synchronization techniques, storage requirements, and prequantization processing. It is apparent that the most critical problem with any TV data compression system centers around the synchronization of the data samples.

Magnetic Tapes

Sixteen Ranger 7 pictures have been placed on magnetic tape. These pictures, including six originals and ten compressed pictures, were acquired from Fred Billingsley, Section 318. Don Weber of Lockheed, Missiles and Space Division, compressed the six original pictures using zero-order, first-order, and run-length

compression techniques. These pictures will be used as standards to test various TV compression systems.

A magnetic tape has been produced with approximately two million uniformly distributed random numbers. This tape will be used for the injection of noise errors into a simulated noisy digital communication channel at a preset probability of error per bit.

OUT-OF-HOUSE TV DATA COMPRESSION STUDIES

The Electro-Mechanical Research Corporation (EMR) study contract 950705 has officially been closed out. The EMR final report has been evaluated with the exception of Appendix B entitled "Synchronization Study." This appendix will be evaluated at the same time synchronization techniques are being investigated and applied to zero-order and first-order TV data compression systems.

Even though a number of fidelity criteria for digital TV systems can be derived, we lack knowledge of how to apply these criteria. This problem occurs in part because we can not delineate the fidelity criteria used by the space scientist to judge TV picture quality.

Video data compression techniques, simple to implement and offering a theoretical data compression ratio of 2:1 to 3:1 as compared to 6 bit PCM, are limited by the noise inherent in the TV sensor. Thus, the actual data compression achievable is much less than what theory predicts and thus renders these simple compression techniques useless with present day slow-scan sensors.

VIDEO MODULATION TEST CONSOLE (VMTC)

The VMTC digital sweep circuits have been modified to achieve better stability. This was accomplished by replacing a power supply with an ultrastable precision reference supply.

The VMTC has been modified so that the digital TV data can be stored on magnetic tape in an IBM compatible format by the digital format converter.

A suitable method of calibrating the VMTC for very low frame rates (on the order of 1/2 hr) has been devised.

MATCHED FILTER INVESTIGATION

The effect of the limiter suppression factor on the performance of a *Mariner* II type data matched filter is being investigated. Fifty laboratory tests were performed and the matched filter data was recorded on magnetic tape. The data has been partially reduced, but no conclusions have, as yet, been made.

TECHNICAL MEMOS AVAILABLE

1. TM 3341-65-1, Reorder No. 65-6, entitled 1620 Error Function explains how the error function $ERF(X) = \frac{2}{\sqrt{\pi}} \int_0^{|X|} e^{-y^2}\, dy$ is calculated and the accuracy obtainable.

2. TM 3341-65-3, Reorder No. 65-9, entitled Limiter Suppression Factor tabulates the limiter suppression factor alpha = $\frac{\sqrt{\pi}}{2}(SNR)^{\frac{1}{2}}\, {}_1F_1\,(1/2,2;\, -\, SNR)$ versus SNR from + 15.0 to - 55.0 db in 1.0-db steps.

3. TM 3341-65-5, Reorder No. 65-30, entitled The Effect of Source Noise on Quantization Accuracy and on PE Statistics describes the effects of sensory noise on the quantization accuracy of a digital TV system and describes an upper bound on achievable data compression of a previous element (PE) encoded system.

4. TM 3341-65-8, Reorder No. 65-144, entitled DADCO/Digitized Analog Tape Computer Program describes a 7094 computer program which reads data in the binary mode from a laboratory-generated, IBM compatible, analog-converted digitized tape, performs logical and arithmetic operations on the data, and rewrites the data on magnetic tape in a Fortran-compatible binary-mode format.

TECHNICAL SUMMARIES AVAILABLE

1. TS 3341-65-1, Reorder No. 65-266, entitled Digital Format Converter describes a device which collects data from various laboratory instruments and records this data on magnetic tape in a format that is compatible with an IBM 7094 computer.

Page Intentionally Left Blank

ADVANCED DIGITAL BULK MEMORY SYSTEM DEVELOPMENT
NASA Work Unit 125-23-02-04
JPL 325-30401-2-3341

During this report period, a proposal for a feasibility study of the Kinelogic helical pack storage technique was received, evaluated, and negotiated with Kinelogic for a total cost of $39,660. The award of a contract to Kinelogic was temporarily delayed due to a loss of $15,000 from the task funding during the third quarter of FY 1965. However, an additional $22,000 has been acquired for this program during the fourth quarter of FY 1965 so that adequate funding is now available and procurement action is again being initiated.

Fairchild Corp., Long Island, N.Y., was visited during this report period for the purpose of investigating an optical recording technique under development by Fairchild.

Activities planned for the next six months consist of contracting the Kinelogic Corp. to begin work on a feasibility study of the Kinelogic helical pack storage technique. Further, the survey of prospective bulk data storage techniques being investigated by industry will be continued.

Page Intentionally Left Blank

MICROELECTRONIC SCIENCE DATA SYSTEM
NASA Work Unit 125-23-02-05
JPL 325-30501-2-3240

HYBRID PACKAGING STUDY, NRT SEQUENCER SYSTEM

The NRT Sequencer system containing integrated circuits and standard components was delivered and subsequently tested to portions of the Mariner C type approval test. The system is shown in Fig. 1 and 2.

The sequencer was checked for proper electrical operation in the laboratory and then carried to the JPL Environmental Facility for testing. The following tests were conducted:

1. Vibration.
2. Shock.
3. Static acceleration.

(Refer to JPL Specification MCD-31598-ETS.)

At the conclusion of the environmental tests, electrical testing was again conducted. The electrical tests included the monitoring of all input-output functions during normal operation and with worst-case voltage margins. There were no noticeable degradations in performance as a result of the environmental tests.

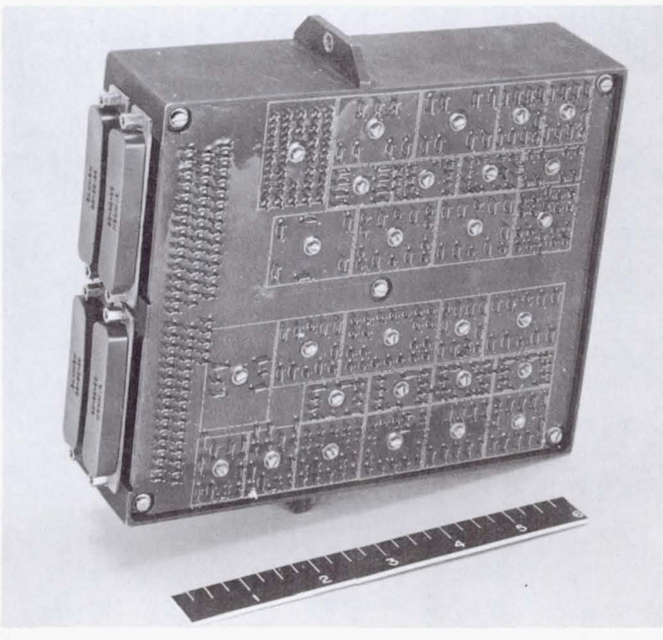


Fig. 1. NRT sequencer — advanced packaging concept (exterior)

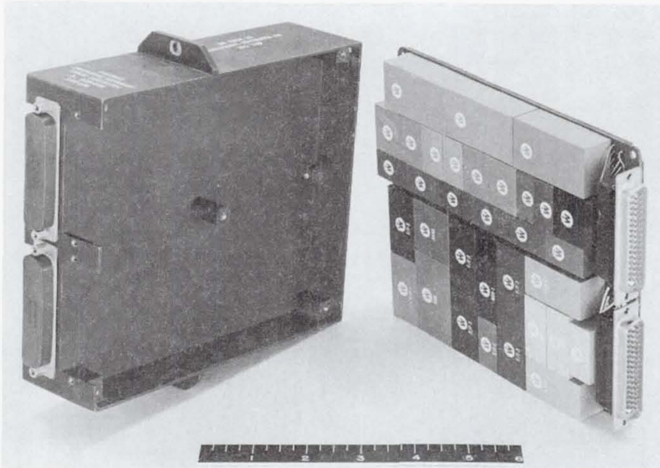


Fig. 2. NRT sequencer — advanced packaging concept (interior)

TESTING SUPPORT FOR SIGNETICS INTEGRATED CIRCUITS

Funds from this task sponsored a reliability program for screening and burning-in Signetics integrated circuit chips used on the high-altitude rocket radar project (NASA Task No. 185-39-05-02). These chips were subsequently designed into a pseudo-noise generator module employing new concepts in three-dimensional packaging of integrated circuits.

The reliability program conducted at the Signetics plant made a contribution to the microelectronics activity in many ways. In addition to generally up-grading the product quality, valuable experience was gained. The use of JPL engineers and inspectors in series with the screening tests at Signetics provided a better understanding of integrated circuit processes in general, and accumulated valuable data on the testing and specifying of screening procedures for enhancing integrated circuit quality.

In summary, the screening effort involved approximately 130 IC chips at a screening cost of about $13 per chip. The general areas of testing were:

1. Centrifuge.
2. Power screening.
3. Serialization.
4. Lot acceptance.
5. Environmental initial data gathering.
6. Thermal shock.
7. Mechanical shock.
8. Operating burn-in.

9. Hermeticity.

10. Application of stability criteria.

11. Dynamic tests.

Of the 130 circuits tested, 22 were rejected; 73 % of the rejects were mechanical-visual.

SURVEY AND EVALUATION OF LOW-POWER DIGITAL INTEGRATED CIRCUITS

A continuous assessment is being made of industry's capability in the field of low-power digital integrated circuits. In May 1964, a survey was conducted at the Amelco Corp. plant in Mountain View, California to assess the manufacturing capability on a newly announced line of low-power integrated circuits (Refer to JPL Conference Report 324-497). An order has been placed for a small quantity of the Amelco circuits and an electrical evaluation of their performance will be made.

FUTURE ACTIVITIES

The survey and evaluation of microelectronic devices which are most adaptable to the specific requirements of a science data system will continue. Low-power, high reliability and interface compatability are among the primary areas requiring investigation. Samples will be procured and assembled into functional elements for evaluation. The evaluation will include studying the device's application to redundant systems for the purpose of reliability improvement.

Page Intentionally Left Blank

RECORDER COMPONENT DESIGN
NASA Work Unit 125-23-02-07
JPL 325-30701-2-3240

MAGNETIC TAPE TEST PROGRAM

This contract ($4,954) is being carried out by Applied Magnetics Corporation. During the early phases of the rocket-radar-recorder project, a problem of tape sticking to heads was discovered. In attacking this problem, the need for quantitative measurements became apparent. A test-rig was accordingly designed and constructed for measuring the static-friction of tape on heads in an inert atmosphere and under varying temperature conditions. Figure 1 is a photograph of this test-rig. Tests were run on 4 different magnetic tapes against a monel head, and on 6 different head materials against 3M type 991 tape. From the sole standpoint of static friction, it turned out that a monel head and Eastman tape provided the best performance. This work was reported in Section Technical Memorandum 324-8 and is scheduled to be published in the JPL SPS No. 37-33 Vol. IV and V.

MAGNETIC TAPE PRECONDITIONING TECHNIQUE STUDY

The purpose of this project is to measure, in terms of drop-out incidence and other reliability aspects, the effect on magnetic tape of cleaning, burnishing, scraping, etc. A specially designed tape cleaner has been bought from Cybetronics, Inc. for the purpose of determining its effect upon tape. Modifications to this device are currently being implemented in order to improve its tape-spooling characteristics.

LOW CAPACITY (UP TO 400K BITS) DYNAMIC STORE

An industry survey for information on such devices yielded replies from about seventy-five different companies. The result of this survey indicates that probably the most feasible device for spacecraft application is a magnetic drum manufactured by IBM for the Titan and other missiles. This drum embodies unusual simplicity and would, therefore, be attractive from a reliability standpoint. It is planned to make a more detailed evaluation of this device.

In order to evaluate the feasibility of short tape loops for this low capacity store application, a breadboard loop transport has been constructed. Seamless mylar belts are being plated with magnetic material and will be evaluated for recording quality and wear endurance.

HYSTERESIS MOTOR AND MOTOR-DRIVE CIRCUIT DEVELOPMENT

The development of a family of hysteresis synchronous motors and associated control circuits for spacecraft applications has been completed. "Staircase" circuits for operation of synchronous motors at very low speeds have been designed, built, and evaluated. These proved to be quite successful and less complicated than expected. A Section Technical Memorandum covering all the work done in this area over the past two years is being edited for publication in July.

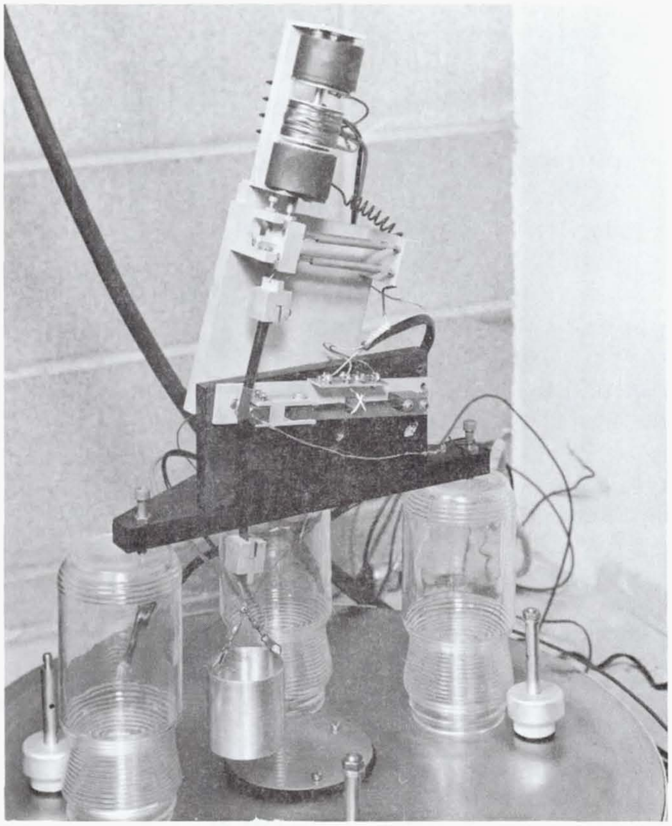


Fig. 1. Magnetic tape test-rig

TAPE GUIDANCE STUDY

This project is one of several aimed at extending the state of the art in terms of digital data packing density on magnetic tape. Analysis of the limitations in packing density reveals tape-position control to be a major item especially where data is to be recovered from parallel tracks simultaneously. A study of various methods of guiding tape over the heads (including some novel ideas) was instituted in 1964 by a CPFF contract to the Kinelogic Corporation. The nine different guidance methods listed below were initially contemplated, and the test-bed was designed so that each method could be implemented by means of interchangeable subassemblies:

1. Groove guidance (System A).
2. Sprocket guidance (System B).
3. Fixed guides w/fixed flanges (System C_1).
4. Roller guides w/fixed flanges (System C_2).
5. Biased roller w/single edge guide (System C_3).
6. Roller guides w/roller flanges (System C_4).

7. Fixed guides w/ double edge trough (System D_1).

8. Roller guides w/double edge trough (System D_2).

9. Crowned rollers (System E).

Because of time and fund limitations, it was decided to study systems A, C_3, D_1, and D_2 in depth and the others only as time and funds permitted. Extensive measurements were also made of tape curvature and width variations in the as-received condition. Some experiments in lapping tape-packs were conducted.

This study is complete and a final report is being prepared.

END-OF-TAPE SENSOR EVALUATION

Indications to date are that a photo-optical system is the most trouble-free and long-lived. Accordingly, a study is being made of available light sources from the standpoint principally of reliability. Shortage of available manpower has curtailed this effort considerably.

Page Intentionally Left Blank

VIDEO DATA RETRIEVAL
NASA Work Unit 125-23-02-09
JPL 325-30901-2-3240

Building of the Video Facility is now virtually complete and should be a very powerful tool to experiment with video compression techniques at a digital level with immediate visual display. This effort has occupied most of the reporting period. There has been a successful hookup to a PDP-7 computer directly to video output equipment.

New concepts have been developed such as conversion of lunar surface reflectivity to elevation data and recovery of attenuated higher frequencies lost by vidicon beam scan. These techniques are used in conjunction with a statistical analysis computer program to judge the probability of a Surveyor spacecraft safe landing.

Effort has continued in coordination with Section 318 (Data Systems) to develop methods to clean up and retrieve higher resolution data from video data such as Ranger VII, VIII, and IX photographs.

Page Intentionally Left Blank

DEVELOPMENT AND APPLICATION OF INTEGRATED CIRCUIT DEVICES
NASA Work Unit 125-23-02-12
JPL 325-31201-2-3341

PHOTON-ACTUATED MULTIPLEX SWITCH DEVELOPMENT

An 18-month contract with IBM for the development of a photon-actuated multiplex switch for telemetry use was completed in November 1964. The switch consists of a gallium arsenide diode photon source and a double emitter silicon transistor which detects the infrared photons and acts as the switch. Efficient photon-coupling is achieved by use of an epoxy medium which also provides mechanical support for the transistor. The assembly, shown in Fig. 1 and 2, is contained in a TO-18 transistor package.

Thirty switches received on the contract were evaluated during the reporting period. A summary of switch parameter goals and parameters actually achieved is given in Table 1. It is unlikely that the specified goals for R_{on} and BU_{EE} can be met in one switch because a design compromise must be made between these parameters.

Table 1. Photon-actuated switch parameters

Parameter (-10 to +85° C)	Value	
	Design goal	Achieved
On resistance	20 Ω w/50 mw drive	30 Ω w/95 mw drive
Off resistance	100 meg Ω	>100 meg Ω
Isolation resistance	100 meg Ω	$>10^{11}$ ohm
Breakdown voltage, BV_{EE}	35 v	20 v
Offset voltage	50 μv	100 μv
Turnon + turnoff time	20 μsec w/RL = 1M	20 μsec w/RL = 10K
Feed-through capacitance	Not specified	6 pfd

The values achieved are useable in many multiplexing applications. Offset voltage is of serious concern only when the switch is used for very low level switching.

The most serious problem with the IBM switches is a gradual increase in "on" resistance with time. This instability was observed in varying degrees in a majority of the switches. Figure 3 is a graph of R_{on} vs time for four typical switches. The curves are typical of the different types of performance observed.

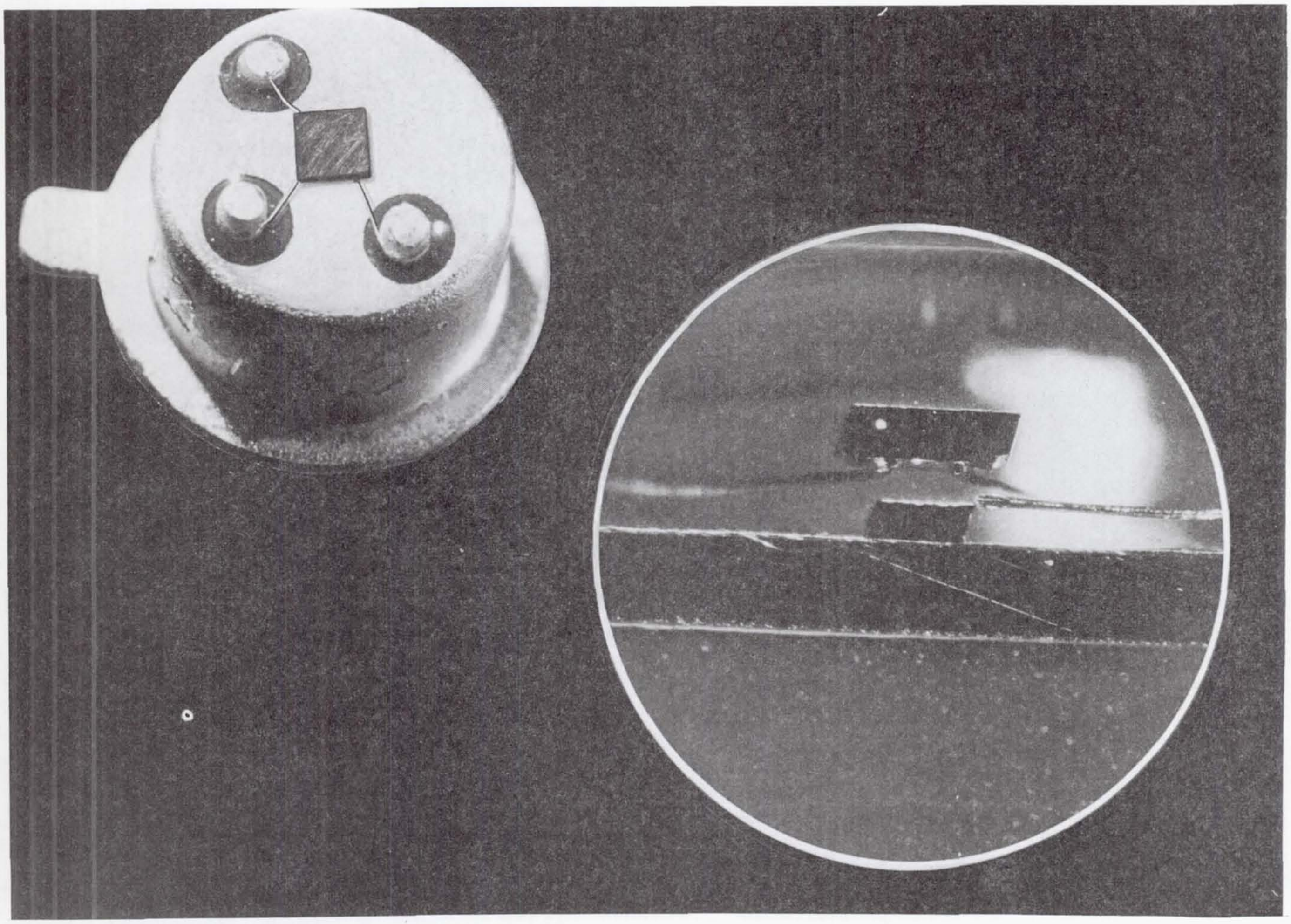


Fig. 1. Photon-actuated multiplex switch on TO-18 header. (The G_aA_s diode is mounted beneath the double emitter transmitter as shown in the insert.)

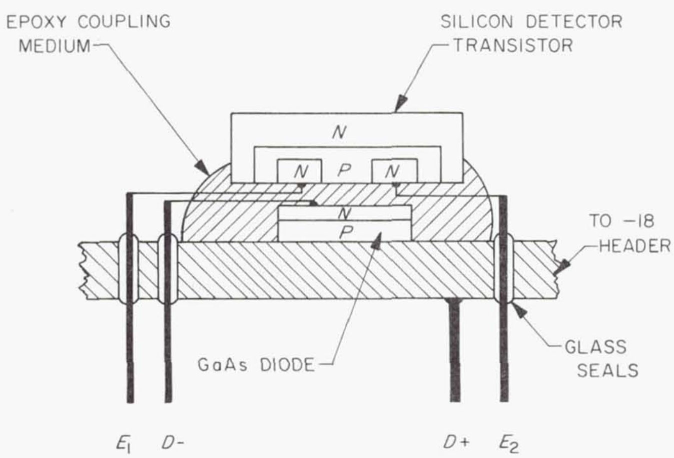


Fig. 2. Photon-actuated multiplex switch structure

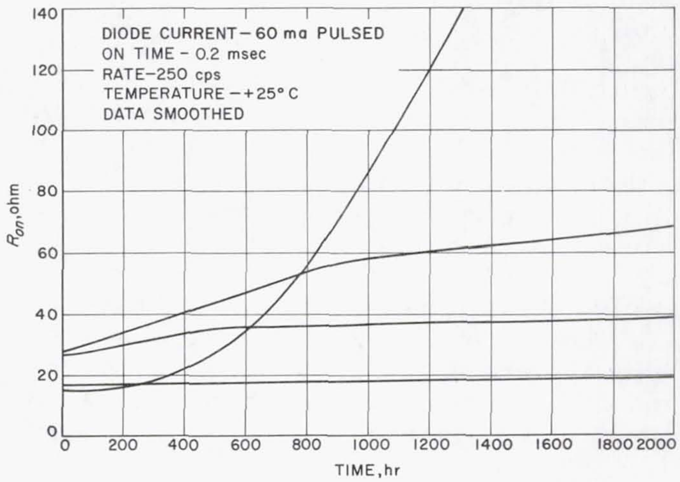


Fig. 3. On resistance vs operating time, four typical photon-octuated switches

It is apparent that more than one type of degradation is occurring. The instability is thought to be caused by a deterioration in photon output from the diode. Westinghouse is continuing to investigate this problem.

To summarize the contractual effort, considerable progress was made by IBM in the development of a new type of multiplex switch that is entirely solid state. It was demonstrated that useful parameters can be achieved in such a device. Certain problem areas were uncovered, however, that require further work before the switch can be incorporated into spacecraft equipment.

A JPL Technical Report has been prepared on this task and will be published soon.

Further work on the multiplex switch will consist of monitoring the life tests at JPL. No contractual work is planned. Another application of photon coupling is discussed below.

PHOTON-COUPLED COMMAND ISOLATION SWITCH

A procurement was initiated in May 1965 for the development of a photon-coupled isolation switch suitable for use in spacecraft command subsystems. The switch will be designed for high reliability and packaged in flat pack form per JPL Design Specification XOY-50469-DSN. This procurement is being jointly sponsored by NASA Work Unit 818-01-04-02-01 (JPL Budget No. 544-40201-1-3340) and JPL 325-31201-2-3341.

The spacecraft command subsystem has many command output lines that feed other subsystems. Each of these lines must be isolated to prevent electrical ground loops. This has been done in the past with relays or transformers. Another means of transferring information (commands) with complete dc and very good ac

isolation is light or photon coupling. This technique affords certain advantages over past methods of isolation.

The primary goal to be achieved in this development is improved reliability. Relays and miniature transformers are among the least reliable components used in spacecraft. An isolation switch utilizing photon coupling would be a 100% solid state device. The modern techniques of grown, diffused, and deposited solid state devices fabricated entirely within a closely controlled environment make possible reliability improvements previously unobtainable.

Another advantage of importance is miniaturization. The present generation of interface switches have been miniaturized about as far as possible. They are not physically compatible with the shape of things to come, that will be integrated circuit flat packages to a great extent. The photon-coupled switch can be made in flat pack forms, thus simplifying subsystem packaging.

The isolation switch shall consist of a silicon transistor, a GaAs diode, and a driver circuit as shown in Fig. 4. When the input of the driver circuit is activated with the proper logic level, the diode becomes forward biased and emits photons which drive the transistor into saturation. When the input is not activated, the transistor is cut off and presents a very high impedance at the output terminals.

The contractual task will be performed in two phases. Phase I requires the contractor to demonstrate the feasibility of the concept by fabricating 20 GaAs diode-silicon transistor pairs which meet the requirements of the specification. In phase II, the contractor integrates the driver circuit and the switch pair into a flat package, and delivers 30 complete isolation switches. Issuance of the solicitation is planned to occur on July 15, 1965, and a contract awarded by mid-October.

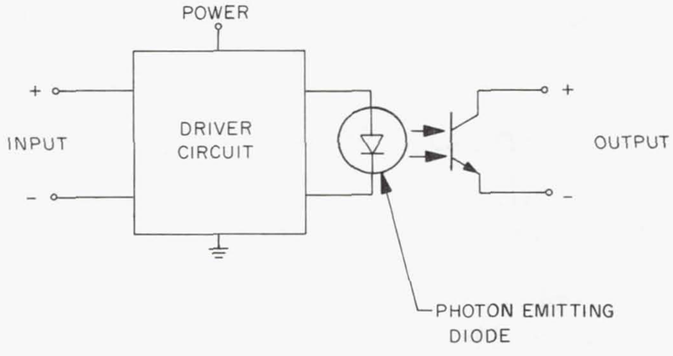


Fig. 4. Photon-coupled isolation switch

MICROELECTRONIC ANALOG TO DIGITAL CONVERTER

A $16,000 fixed price contract was awarded to Autonetics, Division of North American Aviation, in December 1964, for a prototype microelectronic analog-to-digital converter. Autonetics has designed and fabricated the converter during the ensuing 6 months, and is in the process of checkout and final test at present. Delivery is expected in July. The converter will be tested to the requirements of the JPL Specification XOY-50360-DSN, which includes environmental flight qualification at JPL.

The ADC uses the successive approximation method of conversion. Its principal parts are shown in the block diagram in Fig. 5. The speed of conversion is 35 microsec for the 8 bits of information.

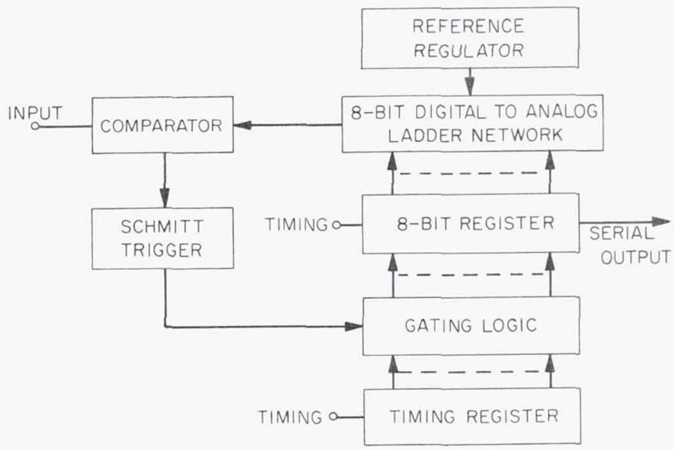


Fig. 5. Microelectronic ADC

The method of fabrication is the unique feature of the converter. Uncased silicon integrated circuits and transistors are attached to 3 thin film substrates which contains precision resistors and the gold interconnection patterns. The substrates are sealed in individual metal cases. The electrical connections between cases are welded and the entire assembly encapsulated. The ADC will weigh about 2-1/2 oz and have a volume of 1.2 in.^{3}

INTEGRATED CIRCUIT SEQUENCER FOR MULTIPLEXING

Proposals for the development of an integrated circuit sequencer for telemetry multiplexing were received in December 1964. Texas Instruments' proposal came closest to meeting the requirement of the JPL specification. Their approach to the basic sequencer stage uses PNP and NPN switching transistors on a monolithic chip. This is not state of the art at present and some development is required. They have a contract with Langley for the development of micropower

logic circuits which also use complementary transistors. If good complementary transistors are achieved on the Langley contract they could be used in the sequencer. The award of a contract has therefore been temporarily postponed pending completion of the Langley contract in October 1965.

LINEAR INTEGRATED CIRCUIT EVALUATION

This program was begun with the purchase of differential and operational amplifiers from a total of six different manufacturers. In addition, thin film resistor networks were purchased from one manufacturer. The purpose was to obtain state-of-the-art linear circuits in order to fully test them and, as far as possible, analyze them. The goals of these evaluations are:

1. To establish a level of confidence in current linear integrated circuits in general.
2. To establish a level of confidence in manufacturers' published specifications on their integrated circuits.
3. To learn linear integrated circuit's tradeoffs, advantages and disadvantages over equivalent discrete circuits, and their peculiarities in general.
4. To learn what can be expected from future linear integrated circuits or at least probable future avenues of improvement.

It soon became apparent that a standard set of significant parameters was not in existance. Nor was there a standard test setup for measuring some parameters. Therefore, there was developed a group of standard test circuits for the measuring of 23 parameters. The test circuits are applicable to virtually any operational amplifier and were used exclusively in the evaluations. The 23 parameters selected for the evaluations are thought to be the most significant and meaningful choices.

Listed below are the circuits tested and the parameters where there was disagreement between specified and measured characteristics. In all cases, the parameters listed did not meet the specified values.

1. Texas Instruments SN 521 (5 units)

   Impedance of inverting input.

2. Texas Instruments SN 522 (5 units)

   Impedance of inverting input.

3. Corning RTN Resistor Network (10 units)

   No discrepancies.

4. CBS Record Circuits (Transconductance Amplifier) (2 units)

   Both units failed to operate above 35°C and eventually catastrophically failed.

5. Fairchild μA 702 (3 units)

   Bandwidth.

   Input bias current.

   Open loop modes of instability also noted.

6. Fairchild μC 101 (3 units)

   Bandwidth.

7. Motorola MC 1525 (5 units)

   Bandwidth.

   Open loop dc gain.

8. Motorola MC 1526 (5 units)

   Bandwidth.

   Input voltage drift.

   Common mode rejection.

In the process of being evaluated now are the Texas Instruments SN 523A, Motorola MC 1528, Fairchild μA-702A, Westinghouse WS123, and Norden NM 1001. More linear integrated circuits will be purchased in the future. Micromanipulators have been purchased to allow interior circuit testing in the future. This has heretofore been impractical and has limited analysis and testing of the circuits. In the next six months it is expected also that previous and future failures will be more intensely investigated. The added depth of interior testing, however, will supplement rather than replace, the afore-outlined blackbox evaluations.

Page Intentionally Left Blank

ADVANCED BUFFER MEMORY SYSTEM DEVELOPMENT
NASA Work Unit 125-23-02-14
JPL 325-31401-2-3341

STATE-OF-THE-ART SURVEY

During the past six months, an extensive survey of industry has been completed in an attempt to establish the current state of the art in advanced solid-state (buffer) memory techniques (a list of industrial concerns and activities is furnished at the end of this report). A preliminary internal technical report has been published documenting the results. This will be updated periodically as new techniques and changes in emphasis occur.

LABORATORY EVALUATION OF ADVANCED MEMORY DEVICES

Laboratory evaluation of two advanced memory devices has begun. These are the TOKO woven plated wire memory plane and the IBM chain-store. Both are thin permalloy film devices and both offer electrically alterable nondestructive readout operation. The immediate goals of this work were to develop the capability of working with high-speed permalloy film memory devices and to gain a detailed understanding of these devices.

Samples of IBM chain-stores were obtained from IBM. A jig for testing these samples has also been acquired. The first problem in testing these samples was to get a word-current driver which was fast enough to get an observable output from the chain-store samples. The recommended work-read current for nondestructive readout operation is a 400-to-500 ma pulse with a rise time of less than 20 nanosec. A sense output of 15-to 20-mv is claimed when this current is supplied.

To exercise the samples, a "one" was written in a given location then read several times (1 to several thousand) and the sense output observed. Then a "zero" would be written and the location read several times and the sense output observed. It was discovered that our chain-store samples gave very marginal NDRO performance. In fact they were acknowledged to be defective samples. We have since received other chain-store samples which have not yet been tested. However, a couple of bit locations did perform satisfactorily. The relationship between read word current rise time and sense output was observed and the transition between DRO and NDRO operation was observed as the read current was increased.

The TOKO woven plated wire plane presented more difficult and perhaps more typical problems. Observing performance of the chain-store was simplified because the samples were of only a few bits each. Thus, none of the problems of a typical array were encountered. The TOKO plane introduced us to these problems. In addition, the TOKO memory is a two-wire system. The requirements on the rise time of the read current pulse are less severe than for the chain-store. A current pulse of 500 ma with a 50-nanosec rise time is supposed to be adequate to give a sense output of 8 mv or more.

The first problem encountered was the separation of the output signal from the noise. A differential input sense amplifier was designed and used in the hope that most of the output noise was common mode. This did not solve the problem. It was found later that the current drivers were putting out a great deal of noise. Tests indicated that the driver noise accounted for most of the output noise. A Computer Test Corp. Model 1500 magnetic core tester was used to drive the plane. Since the tester was designed to drive cores, the small amount of noise observed on the driver outputs would not normally cause any problem. A permalloy film, when rotationally switched, has no threshold level, so driver noise is a serious problem.

A decision remains to be made whether to buy commercial high-speed film drivers or construct some in-house and use the core tester to program them.

INDUSTRY SURVEY OF ADVANCED SOLID-STATE (BUFFER) MEMORY TECHNIQUES

1. Univac, St. Paul, Minnesota. Active in work on flat evaporated permalloy film spot memories. Also have capability in ferrite core and ferrite multi-aperature device memory system technology.

2. Burroughs, Paoli, Pa. Evaporated permalloy film spot memories.

3. IBM, Owego, N.Y. Chain-store, ferrite shmoo.

4. RCA, Needham, Mass. Laminated ferrite memory core to transfluxor production.

5. RCA, Natick, Mass. Core memory system (ground system) fabrication and design.

6. Lincoln Laboratory, Lexington, Mass. Flat evaporated permalloy film research.

7. Bell Telephone Laboratories, Allentown, Pa. Twistors and ferrite aperature plates.

8. Di/An Controls, Inc., Boston, Mass. Ferrite core memory systems and magnetic logic elements.

9. Librascope, Glendale, California. TOKO woven plated wire plane.

10. IBM, Yorktown Heights, N.Y. Research in advanced memory technology; both ferrite and thin permalloy films.

11. IBM, Poughkeepsie, N.Y. Nonmilitary memory systems work. Cores, shmoos, chain-stores.

INSTRUMENTATION (125-24)

ELECTRO-OPTICAL SENSOR EVALUATION
NASA Work Unit 125-24-01-03
JPL 325-40301-2-3230

Due to funding limitations, as reported previously, it was decided to concentrate on the evaluation of a single-type sensor. The sensor chosen is the Westinghouse SEC vidicon. This tube is essentially a vidicon tube with an image intensifier section ahead of the vidicon target. The tube is reported to exhibit as much as 3 orders of magnitude increase in sensitivity over a vidicon with approximately the same resolution capability. The intensifier section lends itself to the study of electronic shuttering and future activity will be devoted to the evaluation of these techniques.

The SEC vidicon was received during the first half of FY 1965; the yoke assemblies were received during this reporting period. A camera head was designed and fabricated which includes a low noise-wide bandwidth video preamplifier and a voltage divider for the imaging section.

The camera head is currently being fitted to the Section 323 image tube evaluation equipment for checkout. The tube evaluation equipment is described in JPL Space Programs Summary 37-30, Vol. IV, page 138, A Facility for the Test and Evaluation of TV Imaging Devices by W. C. Schaefer. A reject quality tube is being used to support initial setup and checkout of the evaluation equipment.

Work during the next fiscal year will include a detailed evaluation of the tube which will consist of the following measurements:

1. Light transfer characteristics.
2. Aperture response (resolution).
3. Spectral response.
4. Dark current characteristics.
5. Storage and lag.

In addition to the fundamental measurements listed above, the following areas of special interest will be investigated:

1. Electronic shuttering.
2. Slow scan operation.
3. Resolution and sensitivity versus imaging section voltage.
4. Useable brightness range with dynamic control.

Page Intentionally Left Blank

PHOTOSCAN SYSTEM
NASA Work Unit 125-24-01-04
JPL 325-40401-x-3230

Work was performed on two major areas during the reporting period: camera-film processor evaluation and a solid-state scan system.

The camera-film processor, procured under contract 950794, was received from Fairchild Space and Defense Systems in March 1965. Functional evaluation was performed as described in JPL Space Programs Summary No. 37-32, Vol. IV. The camera-film processor was originally scheduled for delivery in October 1964, but problems were encountered with the camera portion which delayed delivery. For this reason, no environmental testing has been performed to date.

Additional in-house activity consisted of the design, fabrication, and evaluation of a film scanner, using a GaAs light source and a photo transistor. The results of this work are reported in SPS 37-32, Vol. IV, entitled Film Scan System Using a Solid State Light Source and Light Detector.

One of the least understood problems of film systems for planetary photography is the radiation damage that will result from exposure to interplanetary space for an 8- to 14-mo period. It is believed that laboratory studies supported by a spacecraft sensitometric experiment could provide valuable information regarding the amount of shielding required for a planetary mission. Accordingly, a simple sensitometric device was investigated, the results of which are reported in JPL SPS 37-32, Vol. IV, entitled An Interplanetary Sensitometric Experiment for Radiation Damage Determination.

Due to manpower restrictions, no work is planned for FY 1966 in the area of film cameras, processors, or environmental and radiation effects on film and process chemicals.

Page Intentionally Left Blank

STERILIZABLE, RUGGEDIZED ELECTRO-OPTICAL IMAGE DETECTOR
NASA Work Unit 125-24-01-05
JPL 325-40501-2-3220

In August 1964, Statement of Work No. 3475 and request for proposal were submitted to industry for the study and development of a sterilizable, ruggidized vidicon image detector suitable for use in lunar and planetary missions. The effort requested included two tasks. Task I consisted of study and analysis of the sterilization of photoconductors culminating in a photoconductor capable of withstanding the high temperature sterilization compatibility test. Task II consisted of design and development of a sterilizable, ruggedized vidicon which was to be ruggedized to withstand 3000-g shock.

The statement of work highlights is listed below:

1. Image quality similar to presently used slow scan vidicons.
2. Electrostatic deflection and focus.
3. Eleven millimeter square usable target area in a 1-in. envelope.
4. Low power heater.
5. Minimum weight.
6. Survive storage at temperature between 0 and 21°C at 10^{-6}mm Hg for not less than 18 mo.
7. Survive sterilization:
    a. 3 cycles of 36 hr each at 145 ±2°C in dry nitrogen returning to room temperature conditions between cycles.
    b. 24 hr soak in a mixture of ethylene oxide and freon 12 at 24°C and 35% relative humidity.
    c. As above but at 40°C.

Proposals were received from General Electric, General Electrodynamics Corp., Westinghouse, and Radio Corp. of America.

CONTRACT SELECTION

A team of space television specialists was chosen to review and evaluate the proposals. Included on the team was a consultant, Dr. Bube of Stanford University, an expert in the field of photoconductivity. Based on the inputs from the team, RCA was chosen as the most likely vendor to succeed for the following reasons:

1. They have considerable experience in ASOS material for slow scan vidicons.

2. They do not propose a material research program which could not possibly be completed in the 10-mo time required in the statement of work.

3. They have performed an admittedly short sterilization test, but nevertheless achieved success.

4. They have considerable experience in the use of ceramics and ceramics-modular construction.

NEGOTIATIONS

RCA's initial bid of approximately $250,000 was more than the available funds. However, it was the team's opinion that RCA was best qualified to do both tasks. It was felt that by reducing the quantity of deliverable items at the program conclusion, the bid would be within the allowed budget. Although lack of funds affected the program in magnitude, the design work, fabrication techniques, sterilization, and high impact survival aspects will all be completed. Additional testing will be done to qualify the design in terms of the total sterilization and ruggedization requirements.

Final negotiations with RCA were completed in February 1965, with receipt of the adjusted quote reflecting rate changes. The final dollar figure arrived at was $175,023, and the contract was initiated on May 21, 1965.

Negotiations were commenced on December 15, 1964. The extended period of negotiations was primarily due to the data requirement portion of the contract. JPL is very concerned about getting into a possible sole-source situation with RCA, which would not be difficult with a device such as a sterilizable, ruggedized vidicon. Because of this concern JPL was attempting to avoid a possible sole-source situation by contractually tying up the rights to the developed device and the knowledge gained from said development. Eventually, after much legal consultation, it was decided to risk the sole-source potentiality to get the program under way, since it appeared that no method existed to avoid the sole-source situation. RCA has been in the vidicon business too long and has too many proprietary procedures and materials associated with vidicon manufacture and development.

PROGRAM DEVELOPMENT

The vidicon was developed nearly 18 years ago, and has not been changed substantially until recently. Vidicons have been used only in entertainment and industrial application where no high temperatures or shock environments existed. The development of space photography, using television cameras, has required the industry to develop new techniques in photoconductor and electron gun fabrication for programs such as Ranger, Mariner, and Surveyor, to name a few. Future programs, such as Voyager, will require even newer fabrication techniques because of the much harsher environment. The sterilizable, ruggedized vidicon program was designed to develop a vidicon capable of surviving both sterilization and high impacts, since a sterilizable component would logically find application in a high-impact environment.

SCHEDULE

Figure 1 shows the milestone expected through FY 1966. The work in the beginning of the program emphasizes material procurements, electron gun design, and initial sterilizable photoconductor testing. The initial mating of the photoconductor and the electron gun is scheduled for the second quarter of FY 1966, and prototype delivery is scheduled for the fourth quarter with the final report due in the first weeks of FY 1967. This schedule is predicated upon a May 21 "go-ahead."

PROGRESS

Work has now commenced and is on schedule. Not much time has elapsed since "go-ahead," but some significant steps have been taken.

The electron lens design is complete, as is the deflection design. The original idea for sealing the quartz faceplate to the tube envelope has been changed to a simpler method which is similar to the sealing technique used on commercial vidicons, which has proven very satisfactory.

The design of the heater-cathode structure is proceeding well; some consideration is being given to a directly heated cathode to reduce power comsumption.

Four bids on the ceramics have been requested; two have been received. Very close tolerances were specified, but is apparently no problem.

The evaporation of the initial faceplates for sterilization testing is under way, no results are available at this writing. The facilities for both gas and heat sterilization are ready.

Figure 2 is a rendition of the probable configuration of the vidicon.

The FY 1965 funding has provided only a minimal effort, resulting in less than adequate testing and too few deliverable items for thorough evaluation. The FY 1966 program will augment the FY 1965 program and bring the total effort to a high confidence level by increased environmental testing and evaluation. Long-range plans call for integration of this vidicon in a miniature high-impact sterilizable camera.

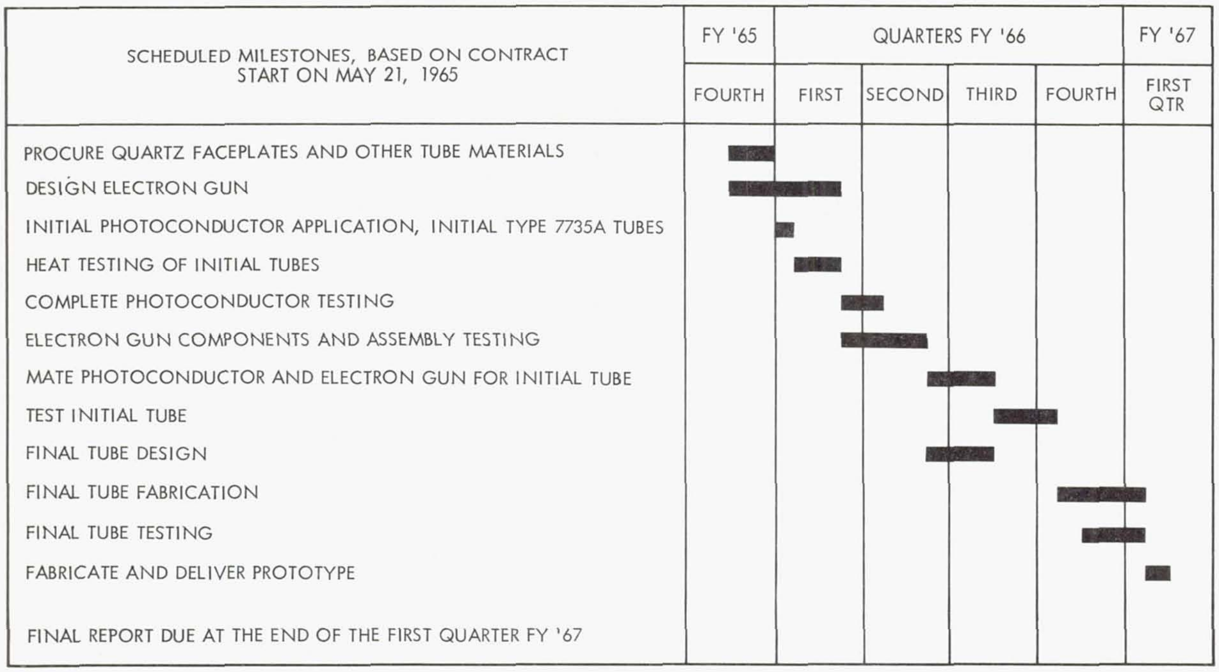


Fig. 1. Sterilizable, ruggedized, electro-optical image sensor milestones

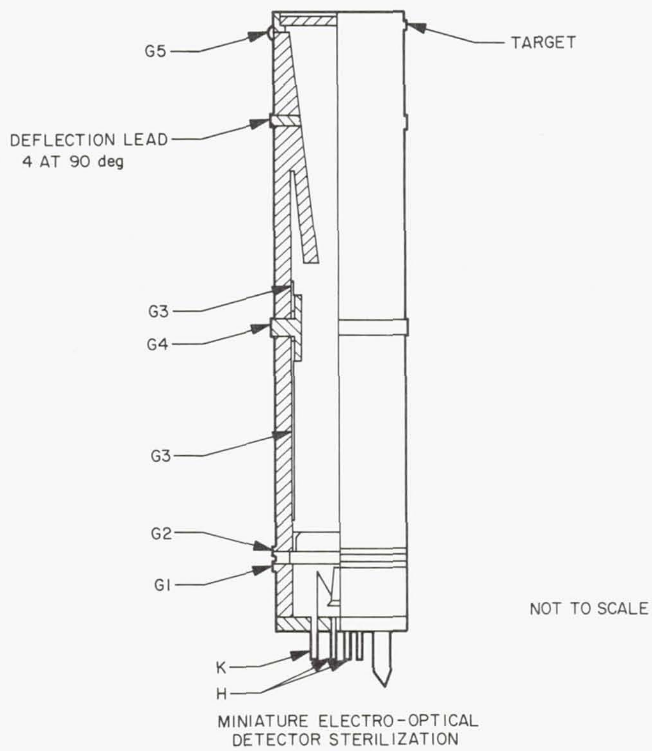


Fig. 2. Proposed 1-in.-diameter electrostatically focused and deflected ceramic vidicon

PHOTOSCIENCE INSTRUMENTS
NASA Work Unit 125-24-01-06
JPL 325-40801-2-3290

Progress during this reporting period has consisted of: (1) continued literature study, (2) experiment design, and (3) establishment of laboratory facilities. Because of budget restrictions, a joint laboratory has been established to support the experimental activities of both this task and lunar spectral photography. Nearly all of the less than 1/2 man-effort available to this task has been utilized for this purpose. The laboratory is nearly completed.

This task is not funded for FY 1966, so no further effort will be expended to achieve the task goals. All manpower will be diverted to lunar spectral photography, OSSA Program 190.

Page Intentionally Left Blank

TEST INSTRUMENT DEVELOPMENT
NASA Work Unit 125-24-03-02
JPL 325-40601-2-3710

This task includes state-of-the-art development work on transducers and associated instrumentation for measurement of force, pressure, acceleration, and temperature as applied to spacecraft and spacecraft component testing. Status of work done on this task during the last six months of FY 1965 includes the following:

ISOLATION AND EVALUATION OF HIGH FREQUENCY PRESSURE TRANSDUCERS

During the last half of FY 1966, several areas in the development of high frequency pressure measurement have been explored.

A method to evaluate overall pressure measuring system response has been devised. It consists of application of known pressure steps by shock tube methods, signal recording on high frequency magnetic tape equipment, and display by transferring the tape recording to an optical oscillograph. This is the same method as used in the data acquisition system set up for measurement of chamber pressures in resonant combustion investigations.

The use of this evaluation procedure has resulted in an increased understanding of the effects of transducer mounting configuration, thermal protection, and vibration isolation on noise and frequency response. Tests using blanked transducers that are capable of seeing inputs other than the measurement for which the transducer was intended have demonstrated the effectiveness of special shock mounts. Noise reductions by a factor of 10 have been realized without compromising the desired signal characteristics.

Several types of ablative coatings have been evaluated as thermal barriers. One of the most promising of these is GE TRV-560 which, when properly bonded to a Kistler transducer, has resulted in thermal drift rates significantly lower than certain water-cooled diaphragm models for short duration runs in combustion chambers.

A paper co-authored by R. M. Clayton and Steve Rogero of Sections 383 and 371 respectively has been prepared for presentation at the 7th Liquid Propulsion Symposium in October, 1965. It is entitled <u>Experimental Measurements on a Rotating Detonation-Like Wave Observed During Liquid Rocket Resonant Combustion</u> and will be published by JPL as Technical Report No. S-9768.

A continuation of this work is expected in FY 1966 as a separate task entitled <u>Pressure Transducer Development</u>. Further advanced areas of interest which may be explored as time permits include a quantitative analysis of pressure measuring system response, a study of thermal effects under controlled heat transfer conditions and an investigation of fast response low pressure transducers for use in plasma and ion propulsion environments.

ULTRAVIOLET SENSITIVE, MULTICHANNEL SPECTROMETER

The multichannel UV spectrometer for shock tube gas studies has been fabricated and is nearly ready for operation. A minor mechanical problem was encountered involving the wavelength adjustment on two of the channels. It is expected that this will soon be fixed and that the instrument will be checked out and installed in the hypervelocity shock tube facility for use in radiant emission studies. It has the unique capability for sensing radiant energy at selected wavelengths between 500 and 8000 angstroms. Its use will be largely in the field of planetary entry vehicle studies.

NARROW BAND IR ABSORPTION PHOTOMETER

The testing of gas core reactor models includes the use of Freon 13 to simulate a heavy reacting gas. An indication of the effectiveness of a given model configuration is the amount of Freon 13 appearing in its exhaust. An infrared photometer of unique design has been constructed which is capable of quantitatively measuring the amount of Freon 13 in the exhaust by detecting its absorption of infrared radiation at a wavelength of 8.25 microns. This instrument was completed early in the calendar year and put to work in support of the Vortex investigation work under OART Task 129-01-11-01 (JPL 329-11501-1-3831) where its performance was in excess of expectations. A description of this instrument and its capabilities entitled An Infrared Photometer for Measuring Freon 13 Density in the Exhaust of a Hydrogen - Freon - 13 Gas Reactor Model by R. Willson and G. Wiker may be found in SPS 37-32, Vol. IV.

RADIATION INSENSITIVE KNUDSEN GAGE

Work on a radiation insensitive Knudsen gage for absolute measurement of very low pressures was started in the first half of FY 1966. A general design was completed, but was not fabricated due to investigation of Micro-Erg Laboratories, Inc., Report No. C63-01, Absolute Pressure Gauge Feasibility Study under contract NAS 5-3212 in which the relative effect of radiation forces with respect to molecular momentum at various low pressures was stated. Since the report appeared to be valid, and indicated an appreciable percent of torque to be caused by radiation pressure at gas pressures of 10^{-6} mm Hg, it appeared that a Knudsen type gage intended to operate at pressures below this figure was not practical. Further investigation indicated the possibility of using activating vanes made of a material, such as silicon or special glasses similar to E.K. Co. Irtran II (polycrystaline zinc sulphide), which is opaque to molecular forces, but transparent to the infrared radiation. Such materials present fabrication problems which have not yet been solved so progress is slow; however, it is our intent to continue with this instrument on a low priority basis in FY 1966.

FREE FLIGHT PRESSURE TELEMETER FOR WIND TUNNEL USE

Further work has been done on the improvement of the pressure transducer and electronic telemetry package for free flight wind tunnel models. The models

consist of 10 and 15 deg half-angle cones with the pressure transducer located in the base. The models tested were usually recovered and served to perform on several flights.

Various tests were conducted in order to evaluate the performance and to compare actual flight data with theoretical prediction. Flights with the transducer entrance blocked served to verify that interaction due to high acceleration and temperature changes was virtually nonexistant at the sensitivity level used. Maximum full scale range of the system is presently limited by the FM bandwidth of the receiver used. However, sensitivities of 80 kc/mm Hg, using a 100 Mc reference frequency, have been easily obtained. Calibration is performed by creating a pressure step within a partially evacuated bell jar and telemetering the signal to the outside. Further information on this telemetry transducer system may be found in SPS 37-33, Vol. IV or JPL TR 32-763, by R. Harrison entitled A Pressure Telemeter for Wind Tunnel Free Flight Pressure Measurements.

Future development plans include alteration of the circuit to accommodate a thermocouple or other temperature transducer for temperature telemetry. Close liaison with J. B. McDevitt of Ames Research Center, as well as with others, is being maintained in order to keep abreast of similar advances in the field.

PRESSURE CALIBRATION

The calibration and accuracy of several oil manometers used for low pressure wind tunnel and shock tube measurements was questioned. An accuracy investigation on the manometers was made on a statistical basis by comparison to known standards. The results of this investigation, together with a description of the apparatus, is given in SPS 37-31, Vol. IV, J. M. Kendall, Sr., Accuracy of the Optical Readout dc 200 Oil Micromanometer. The results of the investigation showed that, in general, the accuracy was better than one micron of mercury, or 0.1%, whichever is greater.

Further work in the area of low pressure calibration is contemplated, particularly in the standardization of gages, such as ion gages for various gases and gas mixtures such as might be used in space environmental simulation.

DEVELOPMENT OF PLASMA SPRAY TECHNIQUES FOR APPLICATION OF HIGH TEMPERATURE THERMOCOUPLES

Recent requirements for temperature measurements on columbium and molybdenum components of a liquid metal heat exchanger loop have necessitated development work in the field of high temperature thermocouple application. Some of the more severe requirements include repeatability of 0.5% at operational temperatures of 2500°F. Attachment without the use of welding techniques was required for application of differential thermocouples.

The approach thus far has been that of plasma spraying using metallic oxides to provide bonding, insulation, and protective covering. Metallic oxides have the desired qualities, however, the application techniques that must be used to produce

the required results leave much to be desired. Some success has been achieved thus far using aluminum oxide for insulation and bonding. It is contemplated that work on technique development will continue in FY 1966 until satisfactory results have been obtained.

HUMAN FACTORS
SYSTEM (127)

Page Intentionally Left Blank

MAN-SYSTEM INTEGRATION (127-51)

GROUND CONTROL STATION FOR ROVING VEHICLE
NASA Work Unit 127-51-01-01
JPL 327-10101-1-3192

The primary objective of the study is to establish a system operating concept for Rover type operations at the DSN. The approach is to conduct a system requirements analysis rather than attacking specific problems for a specific mission: our concern is with the basic problem of remote control for a DSN ground control station. The study contractor will coordinate his efforts closely; however, with the Rover vehicle contractor who may also be responsible for the design and development of the ground station equipment. JPL will be responsible for defining interface relations with existing DSN facilities. The outputs of the study will be used by JPL as the basis for implementing such real time control capability as necessary for immediate (Rover) and anticipated (Voyager) operations.

Procurement activities were initiated in this reporting period. Contractor go-ahead is scheduled for August 1, 1965.

Task Statement 127-51-01-01 on Form 1044 was approved by NASA OART approximately April 15, 1965. A June 1, 1965 contract go-ahead was planned, based on this approval. Delays in fiscal approval and in procurement have resulted in rescheduling. The procurement requisition was approved by JPL on May 25, 1965. A letter was sent to potential contractors on May 18, 1965, and replies were received on June 1, 1965 from which the bidder's list was formed. The RFP package was released on July 2, 1965, and proposals are due at JPL on July 16, 1965. The earliest contract go-ahead date is August 1, 1965.

The RFP asks for a requirements analysis resulting in a conceptual design for a ground control station. The specific program plan and schedule is dependent on the negotiations with the successful contractor. Specific areas of study are considered to include at least:

1. Information requirements for users and operators.
2. Image storage, retrieval, and identification.
3. Command procedures, decisions, and control equipment.
4. Real-time display of image and identification, vehicle status and science, and use of display aids.
5. Operator perception characteristics.

Page Intentionally Left Blank

ADVANCED TECHNOLOGY CONTRACT MANAGEMENT
NASA Work Unit 128-31-01-04
JPL 328-10401-2-3840

The purpose of advanced technology contracts, let by the Liquid Propulsion Technology (RPL) office and the Liquid Propulsion Experimental Engines (RPX) office at NASA Headquarters, is to advance the technology of all phases of liquid propulsion through contracts to industrial aerospace firms. Under the above work unit, JPL engineers (experienced in the liquid propulsion field) provide the technical management of some of these advanced technology contracts. These advanced technology contract management tasks are supplementary to the normal in-house assignments of these engineers on research, advanced development, or flight projects.

In general, the work consists of visits to the contractors plant for technical information and direction, review of monthly progress reports, and quarterly reviews of progress at the contractor's plant, normally in company with the NASA Headquarters Program Manager. In addition, the engineer assists in the preparation of statement of work for proposed new (or continuing) advanced technology contracts, provides technical evaluation of proposals received, and gives technical review and approval to the final reports that are submitted by the contractor. On a bimonthly basis, the engineer submits an informal report to the NASA Headquarters Program Manager to give his technical judgement on the status of the contractors actual effort and results as compared to proposed.

Table 1 lists advanced technology contracts that have been in effect during the last half of FY 1965 and that were technically managed by engineers in the Liquid Propulsion Section (384) of JPL. It is expected that technical management of advanced technology contracts will continue at approximately the same level of effort during FY 1966.

Table 1. Advanced technology contracts

Contract number	Contract name	Contractor	Contract period	Contract amount, thousands of dollars	JPL technical manager
NAS 7-97	Development of Catalyst for the Thermal Decomposition of Hydrazine	Shell Development Company	February 1964 to December 1964	49	T. W. Price
NAS 7-102	Study of Static and Dynamic Seals for Liquid Rocket Engines	General Electric Company	October 1964 to July 1965	150	R. S. Weiner
NAS 7-107	Advanced Valve Technology for Spacecraft Engines	Space Technology Laboratories	November 1964 to July 1965	150	L. R. Toth
NAS 7-113	Protective Coatings for Refractory Metals	IIT Research Institute	December 1964 to September 1965	125	R. D. Cannova
NAS 7-149	Study of Zero Gravity Positive Expulsion Techniques	Bell Aerosystems Company	May 1964 to February 1965	79	R. N. Porter
NAS 7-169	Investigation and Development of Propellant Feed Systems for Manned Space Vehicles	Aerojet-General Corporation	December 1964 to June 1965	50	R. N. Porter
NAS 7-262	Refractory Thrust Chambers for Spacecraft Engines	The Marquardt Corporation	February 1964 to December 1964	189	W. H. Tyler
NAS 7-304	Chamber Technology for Space Storable Propellants	Rocketdyne	July 1964 to July 1965	402	C. R. Foster
NAS 7-305	Experimental Auxiliary Rocket Engines	Bell Aerosystems Company	July 1964 to June 1965	789	D. D. Evans
NAS 7-372	Study for Development of an Experimental Hydrazine Auxiliary Rocket Engine	Rocket Research Corporation	April 1965 to April 1966	194	T. W. Price
NAS 7-373	Advanced Pyrolytic Spacecraft Rocket Chamber Materials	The Marquardt Corporation	May 1965 to July 1966	200	W. H. Tyler
NAS 7-376	A Theoretical Investigation of Liquid B	Aerojet-General Corporation	June 1965 to March 1966	63	R. A. Rhein

CHEMICAL PROPULSION (128)

Page Intentionally Left Blank

LIQUID PROPULSION TECHNOLOGY (128-31)

ADVANCED SPACECRAFT PROPELLANTS
NASA Work Unit 128-31-05-01
JPL 328-10501-1-3840

One of the more promising propellant combinations for future spacecraft applications is the oxygen difluoride (OF_2) and diborane (B_2H_6) system. This combination offers potential payload increases of 25 to 30% over Earth-storable propellants. In addition, OF_2 and B_2H_6 can be stored as liquids in a space environment by means of passive control of the propellant tank outer surfaces, and the two propellants have overlapping liquid ranges. The main disadvantages of the propellant system are the toxicity and consequent safety problems of both the OF_2 and the B_2H_6, the corrosiveness and associated handling problems of the OF_2, and the high combustion temperature. The initial objectives are to develop propellant handling techniques, to develop injectors readily scalable to various thrust levels and amenable to throttled operation, to determine performance and heat transfer, and to investigate thrust chamber and nozzle cooling problems.

After completing the Cavea-B and hydrazine/hydrazine nitrate monopropellant work during the first half of FY 1965, modification of a test cell for the OF_2-B_2H_6 experimental program was begun. Because of the "mild" cryogenic nature of both propellants, provision must be made to cool them. For OF_2, which is available only in gaseous form, the refrigeration for condensation and maintenance of the OF_2 in liquid form will be supplied by means of a liquid nitrogen (LN_2) bath. The OF_2 is liquified only for a test and will normally be stored as a gas. The container for the LN_2 bath will be an open mouthed tank for the propellant tank and an open trough for the propellant lines, valves, and other hardware. The LN_2 bath, the OF_2 propellant tank, and the propellant valves are on hand and assembly of the system is underway.

The B_2H_6 is available as a liquid, but must be maintained at a low temperature to prevent thermal decomposition. At a temperature of -10°F, B_2H_6 can be stored for several months; at -100°F it can be stored indefinitely and the vapor pressure is only about 40 psia. The refrigeration technique chosen consists of spraying liquid nitrogen inside a double-jacketed, insulated tank that completely encloses the high pressure propellant tank. Automatic control of the system is done by a commercially available device. This device consists of a solenoid valve in the liquid nitrogen line that is controlled by a temperature probe within the double-jacketed tank. Preliminary tests of this refrigeration system have been made. The internal temperature of the B_2H_6 propellant tank was maintained at -100°F for 30 hr. Except for some areas of excessive frost buildup, which can easily be cured by better insulation techniques, the system performed satisfactorily.

The B_2H_6 propellant line, valves, etc., must also be cooled if two-phase flow during short tests is to be avoided. This will be done by jacketing these components and flowing cold gaseous nitrogen through this jacket. The jacket parts are now being made and should be available early in July.

Difficulty in procuring two major pieces of equipment have delayed the entire program. These are: (1) a chemical scrubber to remove HF from the exhaust gases and (2) liquid level measuring devices for the propellant tanks. An attempt was made to purchase an off-the-shelf scrubber, but preliminary inquiries by the Procurement Division indicated this item would cost \$10,000 to \$20,000, exclusive of the design, fabrication, and installation of the necessary piping and auxiliary equipment. An in-house preliminary design and cost estimate showed that a suitable scrubbing system could be designed, fabricated, and installed for about \$15,000. The in-house design has been completed and the drawings released for bids. The scrubber will be installed during the first quarter of FY 1966.

Difficulty was experienced in finding a vendor who could meet our liquid level measurement specifications. The main problems were materials compatibility and gage accuracy. Just before the end of the fiscal year a satisfactory vendor was located. Lack of this equipment has prevented the final design of the propellant tank flanges and, hence, the final tank installations. As soon as the liquid level sensor physical dimensions and positioning in the tanks are finalized, the flange design can be completed. The flange drawings will be completed early in July and the installation of the liquid level sensors should be completed before August.

During this report period of OF_2-B_2H_6 work has progressed at a slower rate than planned for several reasons. These are: (1) procurement and JPL Plant Services work delays because of prolonged 328-job number funds freeze, (2) less engineering time available than anticipated because the work statement preparation and proposal review phase of a NASA advanced technology contract took place during this period, (3) less technician time available than planned because of the JPL manpower limitations, and (4) the senior technician who has worked on this program since its beginning has left JPL to accept a position with industry.

During this report period the JPL theoretical rocket performance computer program was modified to make it compatible with the JANAF thermochemical data. This is a step towards resolving the experimental performance discrepancies (expressed as a percentage of theoretical performance) experienced in the past between JPL and industry. Additional time has been expended working with the United Aircraft Corporation computer program, which treats the one-dimensional nonequilibrium flow of a chemically reacting gas. This program has proven to be difficult to use because each problem to be solved requires different data manipulations, and few useful results have been obtained.

Modification of the test cell will continue during the first quarter of FY 1966. Installation of the propellant feed systems and preliminary flow tests should be completed during the first quarter. Final injector and instrumented thrust chamber designs are near completion and this hardware will also be fabricated during the first quarter. Initial engine firings should take place early in the second quarter.

RESONANT COMBUSTION
NASA Work Unit 128-31-06-01
JPL 328-10601-1-3840

The resonant-pressure distribution measurements on the 11-in.-diameter engine using RMIR injector 5 with Corporal propellants have been completed for the 300-psia operating condition (nominal steady state design chamber pressure). The results may be summarized by the following:

1. The pressure wave-to-chamber wall intersection was found to curve in the direction of wave rotation with the nozzle end of the intersection leading the injector end by approximately 40 deg circumferentially. The wave-to-injector face intersection was found to be nonradial and to extend into the central area of the face, though the definition of the intersection was poor in this area. These results are illustrated in Fig. 1a.

   The tangential component of the intersection velocity is 6160 ft/sec, which corresponds to a Mach number of 1.76 based on an acoustical velocity of 3500 ft/sec for the chamber gases.

2. The observed pressure ratio across the wave front (ratio of peak-to-minimum pressures during a wave rotation period) varied along the chamber wall from in excess of 20:1 near the injector to approximately 4:1 near the nozzle entrance. The pressure ratio at the face varied from greater than 20:1 in the outer half radius to less than 4:1 near the center. Figure 1b summarizes these results. Also depicted on this figure is the nonsymmetrical wave form of the disturbance. The frontal rise time is believed to be less than 3 μ sec.

   It is noted that the transient nature of the disturbance and the severe thermal and vibration environment encountered during resonant conditions makes precise amplitude measurements difficult to obtain.

The pronounced steepening of the intersection and the increased amplitude of the disturbance near the corner of the chamber boundaries (i.e., junction of the injector face and chamber wall boundaries) are interpreted to be indicative of the presence of the major portion of the driven front in this region of the combustion volume. These data also suggest a skewed front orientation to these corner surfaces.

While these results do not fulfill an ultimate objective of determining the general applicability of the rotating detonation-like wave concept to explain the high-amplitude, high-frequency combustion pressure distrubances associated with resonant combustion, it is felt that they are consistant with that hypothesis.

Attempts to initiate resonance during low p_c (60 psia) operation of this engine failed; apparently because the initial high amplitude pressure disturbance, which is precipitated by the bomb, stops the injected propellant flow for several milliseconds. By the time flows and combustion are reestablished, the disturbance amplitudes have decayed to an insufficinet level for coupling with the fresh reactants. Further attempts

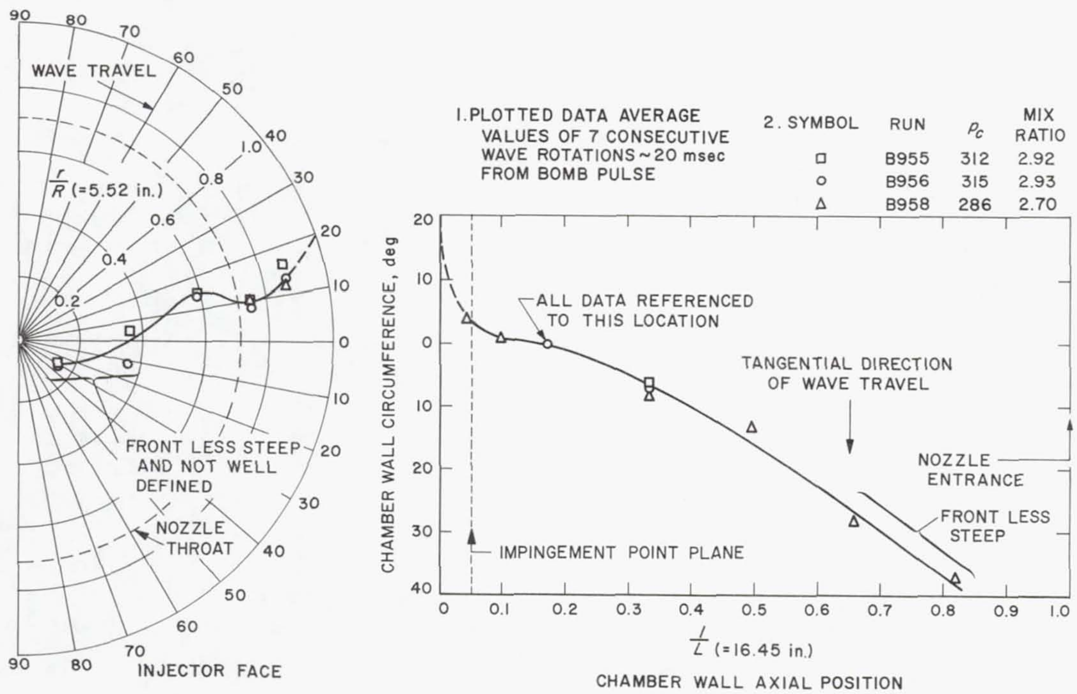


Fig. 1a. RMIR injector No. 5 with SFNA plus corporal fuel
Intersection of resonant combustion wave
with chamber boundary

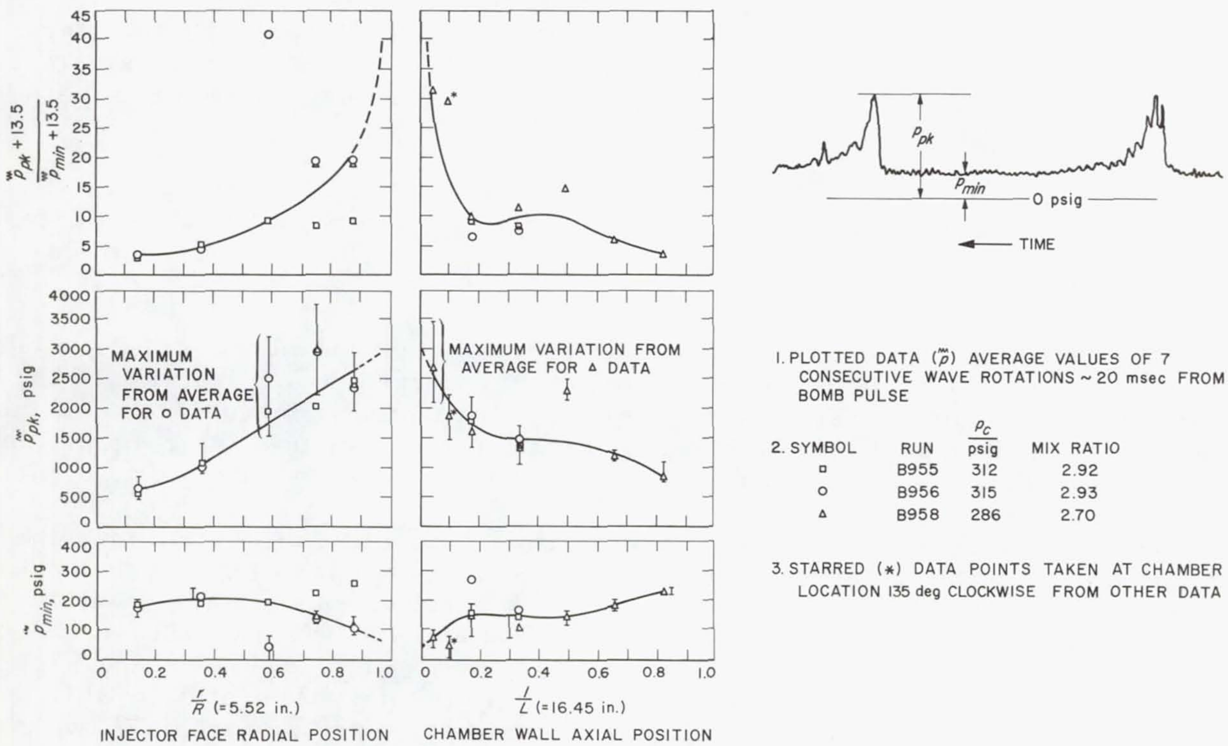


Fig. 1b. RMIR injector No. 5 with SFNA plus corporal fuel
Resonant combustion pressure amplitude vs
chamber boundary position

to operate the current engines of this program at reduced p_c (hence low loading density) have been postponed to get on with the study at near design flow conditions.

Experiments are in progress with RMIR injector 7 substituted for injector 5. These experiments are being made using the 11-in. engine hardware at 300 psia chamber pressure but with the N_2O_4 plus N_2H_4/UDMH (50/50 fuel blend) propellant combination. Because the injector had not previously been operated with these propellants, a series of firings was conducted to establish the steady state performance characteristics of the engine and to verify that resonance could be established with the bomb device. It was determined that the engine exhibited a high relative combustion performance (96 to 98%) and that resonant combustion could be initiated.

It is intended that additional measurements will be made on this engine to determine whether the rotating pressure wave is imparting a circulatory motion to the chamber gases. The generation of a strong vortex could yield substantial effects on injection, heat transfer, mass discharge from the nozzle, and wave propagation. An additional engineer has been assigned to the project, who will concentrate on this phase of the program. It is noted that these measurements will require the development of additional diagnostic techniques.

The modifications to RC injector 1 and to the 18-in. chamber assembly (cf. second quarter report) are complete; however, procurement and fabrication for necessary test stand revisions are still in progress. These revisions are expected to be completed during the first half of FY 1966.

The analytical work under the contract with Professor Agosta is proceeding according to schedule. The initial task, formulation of a steady-state one-dimensional combustion model, has been completed. The computer program functions satisfactorily on JPL's IBM 7094 computer, and is available on lab for steady-state combustion calculations. The program can be adapted to various propellants and motor geometries. Present work, under the contract, concentrates on nonsteady combustion behavior.

Progress has been made on the following reports:

1. Rupe, J. H., An Experimental Correlation of the Nonreactive Properties of Injection Schemes and Combustion Effects in a Liquid-Propellant Rocket Engine, Part I: The Application of Nonreactive Spray Properties to Rocket Motor Injector Design, Technical Report 32-255, Jet Propulsion Laboratory, Pasadena, California (in production).

2. Clayton, R. M., Rupe, J. H., An Experimental Correlation of the Nonreactive Properties of Injection Schemes and Combustion Effects in a Liquid-Propellant Rocket Engine, Part VI: The Relation Between the Starting Transient and Injection Hydraulics, Technical Report 32-255, Jet Propulsion Laboratory, Pasadena, California (in draft).

3. Rupe, J. H., An Experimental Correlation of the Nonreactive Properties of Injection Schemes and Combustion Effects in a

Liquid-Propellant Rocket Engine, Part V: On the Influence of Vanes on Combustion and Combustion Stability, Technical Report 32-255, Jet Propulsion Laboratory, Pasadena, California (in draft).

4. Performance evaluation of RC injector No. 1 (in draft - to be published as Technical Report).

5. Rupe, J. H., Evans, D. D., Designing for Compatibility in High-Performance Liquid Propulsion Engines, Astronautics and Aeronautics, Vol. 3, No. 6, June 1965.

6. Clayton, R. M., Rogero, R. S., Experimental Measurements on a Rotating Detonation-Like Wave Observed During Liquid Rocket Resonant Combustion. This paper will be presented to the 7th Liquid Propulsion Symposium, Denver, Colorado, October 19 to 21, 1965 and will be published as a Technical Report. The essentials of this paper were also presented at the AFOSR Contractors Meeting on Combustion Dynamics Research; held at Patrick Air Force Base, Florida, June 1 to 4, 1965.

ATOMIZATION AND INJECTOR HYDRAULICS
NASA Work Unit 128-31-06-02
JPL 328-10701-1-3840

An evaluation of the colorimetric apparatus, a device capable of measuring the color density of local spray samples, was completed during this period. It was found that, by use of suitable calibration data concerning the dyed miscible liquids used to form the spray, the color density determined by this technique can be accurately related to the mixture ratio of the local sample. Use of this device, in conjunction with a spray sampling apparatus, thereby extends the applicability of the sampling technique to miscible as well as immiscible nonreactive fluids. By use of this apparatus mass and mixture ratio information were obtained from the sprays produced by two different injector configurations that were furnished by the Gas Side Boundary Phenomena work unit (NASA Work Unit 128-21-06-03). This effort was carried out as part of a continuing support activity that this work unit is intended to provide.

A test series was conducted to find out the significance of the absolute density of the nonreactive fluids used on the resulting mass and mixture ratio distributions in the spray. It was found that consistent, reproducible results could be obtained if only the test liquids used had the same density ratio as that of the propellants being simulated. This result will be useful in future work involving spray sampling, particularly where propellant densities cover such a range that they cannot be readily simulated by conventional nonreactive fluids.

A comparison of the data obtained from two identical flow configurations in which miscible and immiscible test fluids were used is now in progress. It is anticipated that such an evaluation will corroborate the results of a brief investigation made a few years ago and will improve the confidence in the two alternative testing procedures.

Work continued on a JPL Technical Report titled "An Experimental Correlation of the Nonreactive Properties of Injection Schemes and Combustion Effects in a Liquid Propellant Rocket Engine: Part IV Relating the Injection Pattern to Heat Transfer to the Combustion Wall." At present, the report is approximately 50% complete.

To extend the usefulness of the spray data already obtained, the effects of practical design constraints imposed on injector configurations as well as the consequence of injector fabrication errors on the resulting spray properties will be evaluated. Measurements of mass and mixture ratio distributions in sprays will be made to determine the consequence of misalignment of orfices and the degradation of hydrodynamic jet characteristics. Jet properties from new orifice configurations will be evaluated by use of a flat plate probe. Analytical studies of free jet development will be continued. Development of a drop size measuring technique will be pursued when such a scheme is found.

Page Intentionally Left Blank

GAS SIDE BOUNDARY PHENOMENA
NASA Work Unit 128-31-06-03
JPL 328-10801-1-3840

EXPERIMENTAL PROGRAM

Data from 200 tests of the enclosed combustor have been logged, and heat transfer rates calculated. Propellants were methanol and white fuming nitric acid. The mass and mixture ratio distributions of the spray used in this combustor have been measured using nonreactive fluid sampling techniques as a part of the Atomization and Injector Hydraulics work unit (NASA Work Unit 128-31-06-02). The existence of a liquid film on the face of the heat transfer probe under some conditions was verified both by high speed motion pictures taken of the burning spray impinging on the probe and by tests using a probe with very low thermal capacity. These latter tests indicated that the film became discontinuous at higher wall temperatures. An analogous phenomena has been observed in rocket engine heat transfer tests in recent years.

An attempt was made to measure the surface temperature of a burning film of mixed propellants. Although some useful data were obtained, the experiment could not be developed to produce sufficient information to justify the time required and was abandoned.

The enclosed combustor was described and some initial heat transfer data presented in SPS 37-32, Volume IV. The heat transfer data obtained to date will be analyzed and correlated with spray properties (particularly local mass flow rate).

Starting July 15, a facility modification will be started to accommodate an additional experiment in the test cell. Concurrently, the enclosed combustor will be replaced by a rocket engine thrust chamber so that heat transfer data may be obtained at 100 psia chamber pressure using the same injection device and the same propellants as were tested in the enclosed combustor. As a result of the limited technician support available to the project, it is anticipated that this thrust chamber experiment will not be ready for testing until the second quarter of FY 1966.

ADDITIONAL PUBLICATION

A paper was prepared and presented at the AIAA Propulsion Specialists Conference in June 1965 with R. W. Rowley and W. H. Tyler as coauthors. This paper presented information derived from the small thrust chamber project that provided the basis for the Gas Side Boundary Phenomena work unit and from information generated by the ALPS Combustion Devices work unit (available as AIAA Paper No. 65-586). This paper will be published as JPL TR 32-750 in revised form in the near future, including additional data obtained after publication of the preprint.

Page Intentionally Left Blank

REACTION MECHANISMS IN SPRAYS
NASA Work Unit 128-31-06-04
JPL 328-10901-1-3840

The objective of this work unit is to study the preignition chemical reaction of oxygen difluoride (OF_2) with diborane (B_2H_6) and, later, to study the reactions of other rocket fuels and oxidizers. A literature survey was made that included the chemical reactions of OF_2, the oxidation chemistry of diborane, and a discussion of some of the physical properties of chemical species containing any combination of boron, hydrogen, oxygen, and/or fluorine. A report covering this literature survey is now in rough draft form.

A chemistry laboratory facility has been prepared for conducting the experimental part of this work. An existing test cell was used, necessary utilities were provided, and the fume hoods and laboratory cabinets were installed. Presently, the vacuum rack glassware is nearly completed and the various other equipment, such as a gas chromatograph, an electronic vacuum gage, and an infrared spectrometer are being incorporated into the system. The work during the next 6 mo will be concentrated primarily on the study of the preignition reactions in the OF_2-B_2H_6 system. The objectives are to determine the reaction rates and products. Should the system be adequately described before the end of this period, then the system of OF_2-B_5H_9 would be studied next to develop general knowledge of flourine compound - borane compound reactions.

Page Intentionally Left Blank

SOLID PROPULSION TECHNOLOGY (128-32)

ADVANCED TECHNOLOGY CONTRACT MANAGEMENT
NASA Work Unit 128-32-01-01
JPL 328-20101-2-3810

Under this task, the following contracts or grants are being managed or monitored technically for Codes RPS and RPM at NASA headquarters:

"Upper Stage Applications of Advanced Solid and Hybrid Propellant Motors," NAS 7-375 at Lockheed Missiles and Space Company.

"Hybrid and High Energy Solid Motors for Upper Stage Applications," NAS 7-374 at Douglas Missiles and Space Systems Division.

"Medium Temperature Gas Injection Thrust Vector Control," WO-1725 at Naval Ordnance Test Station.

"High Performance Nozzles for Rocket Motors," NAS 7-296 at the United Technology Center.

"Studies on Ignition and Flame Propagation of Solid Propellants," NAS 7-329 at United Technology Center.

"Igniter Heat Transfer Studies," NAS 7-302 at United Technology Center.

"Low Pressure Combustion and Ignition," NsG 200-60 at Princeton University.

"Ignition and Combustion of Metal Wires," NAS 7-353 at United Aircraft Corporation.

"Study of Metal Combustion," WO 3033 at Naval Ordnance Test Station.

"Pre-ignition and Ignition Processes of Metals," NsG 641 at Princeton University.

"Synthesis of Nitramine Polymers for Solid Propellants," NAS 7-293 at Rocketdyne.

"Uncoated SPO Propellant Development," NASw 1130 at Thiokol, Elkton Division.

During the next six months, work will be phasing out to completion on WO-1725 and NAS 7-296. It is anticipated that at least two new contracts will be negotiated by NASA-WOO for technical management by JPL.

A report, Summary of the Meeting of the Panel of Reliability of Large Solid-Propellant Motors, TM 33-219, by C. L. Robillard was published on May 10, 1965. Quarterly technical status reports on all contracts and grants are submitted to headquarters Codes RPS and RPM.

JPL was represented at the Interagency Chemical Rocket Propulsion Group/ Solids Subgroup meeting as Sunnyvale, California on April 8 and 9, 1965 for an exchange of information on solid propellant research and development projects among the NASA, Army, Navy, and Air Force.

Effort on contract management during the next half fiscal year is anticipated to continue at the same level, i. e. , at a total one man-year level.

ROCKET MATERIALS AND COMPONENTS DEVELOPMENT
NASA Work Unit 128-32-03-01
JPL 328-20201-2-3810

BATES MOTOR TESTS

The results of the beryllium propellant tests conducted last summer in the Rocket Propulsion Laboratory (RPL), Edwards Air Force Base (EAFB) toxic test area, indicated that nozzle throat erosion was not a serious problem. The results and conclusions of these tests were published in SPS No. 37-29, Vol. V. Because these firings were at near sea-level conditions, it became desirable to evaluate the beryllium propellant performance on nozzle materials at high altitude conditions. An opportunity to do so presented itself when RPL offered JPL a chance to join them in a beryllium test program at AEDC, Tullahoma, Tennessee.

Propellant

RPL will test the double-base Be-TAX-system. JPL will test double-base Be-AP and Be-CTPB-AP systems, based on the results of the tests last year. RPL will use the BATES motor chamber; therefore, to make direct comparison with our RPL firings and because the hardware is available, JPL decided to use the BATES motor also.

Nozzle

The previous beryllium tests used high density graphite throats (Graph-i-tite GX) that were very successful. Therefore, it was decided to use the same throat material to compare the results with the previous tests. The exit cone material is a molded chopped silica/phenolic material which was chosen based on previous test results with aluminized propellant systems. Figure 1 presents a view of the nozzle assembly. The nozzle design is based on using a minimum number of aft closures in conjunction with an ease of nozzle assembly. After each firing, the throat insert can be removed, a new one bonded in place, and a new exit cone attached for the next firing.

Test Plan

To best use the test time available, the following objectives were established:

1. Direct comparison of nozzle performance at altitude between a double-base beryllium propellant and a composite berylliumized propellant, and aluminum reference propellants.

2. Determine specific impulse variation with motor chamber pressure.

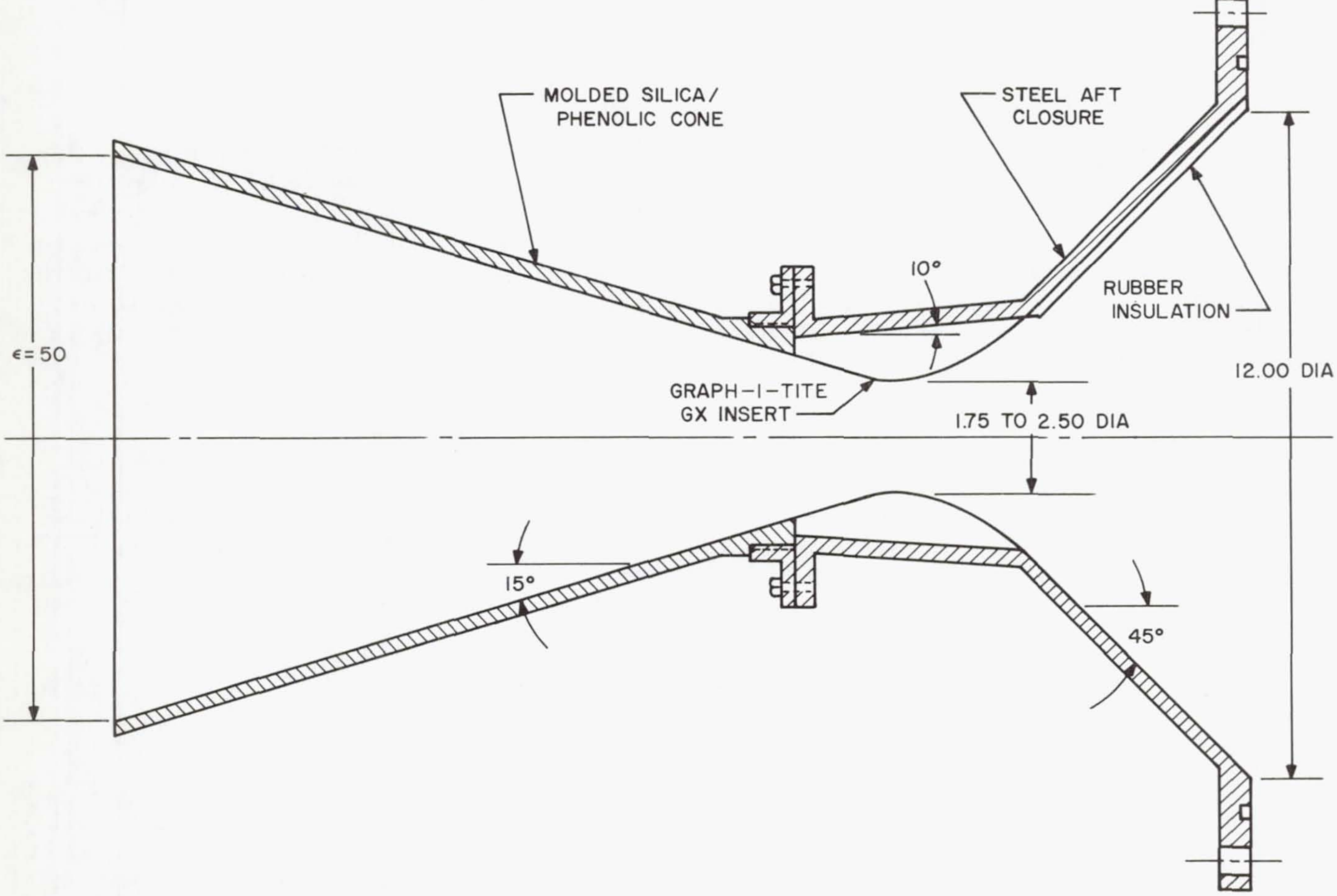


Fig. 1. Nozzle assembly for altitude tests of beryllium propellant

To carry out these objectives, the following test procedure will be used. All the firings will be made at nozzle expansion ratios of 50:1.

1. Test each beryllium system at chamber pressures of 600 and 300 psia.

2. Test an aluminum reference system at the same chamber pressures.

3. Compare the performance and determine whether to increase or decrease the 300 psia chamber pressure level.

4. Once the minimum pressure (with still acceptable performance) level has been determined, test another motor at this level to verify the results.

Figure 2 presents a general variation of specific impulse efficiency with motor chamber pressure. Data has been obtained from various test sources that indicate that beryllium propellant efficiency drops off at approximately 500 psia. It is believed that by keeping the various test parameters constant, that a definite drop-off point in efficiency can be established. Therefore, the motors will be tested so as to define the curve shown on Fig. 2. This is the first time a program of this nature has been conducted with beryllium propellants at altitude.

Procurement

All motor hardware, including the propellant grains, have been procured and shipped to AEDC. JPL will test a total of 20 motors including the aluminum reference firings. The cost of the propellant and nozzles is shown in Table 1.

Table 1. Costs of propellants and nozzles

Propellant or item	Material/no.	Cost, dollars
TP-H-1092	Beryllium/6	41,760.00
TP-H-3062	Aluminum/2	2,000.00
ARCOCEL 319BR	Beryllium/6	18,500.00
ARCOCEL 321	Aluminum/2	6,426.00
TP-H-3135	Aluminum/2	2,000.00
Nozzles	Steel/graphite/silica/20	18,283.00

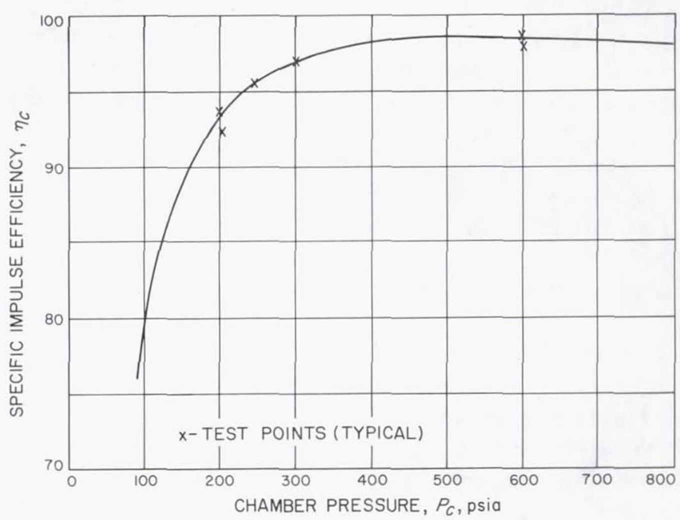


Fig. 2. Specific impulse efficiency variation with chamber pressure

Future Activities

It was anticipated at the beginning of the program to start testing in April, but because of higher priority tests at AEDC the test program will not begin until the first part of August.

CAMERA SYSTEM FOR VIEWING NOZZLE THROATS

To develop a useful tool to study nozzle throat erosion phenomena, some preliminary camera tests have been made to demonstrate the feasibility of the idea. A system has been developed and tested that allows a camera to be placed in the exhaust stream and photograph the nozzle throat, on the centerline, during firing.

Only small-scale motors, 5 x 6 tubulars, have been used thus far to demonstrate the technique. The camera has not been damaged during the runs, and the nozzle throat can be clearly seen in the movies.

A larger camera box is being designed to accommodate large high-speed cameras. The box will be water-jacketed and pressurized inside with an inert atmosphere to keep out exhaust gases.

Future Activities

Further tests are being planned with large motors and various filters on the camera as well as film speed to better define the throat characteristics during firing. It is believed that this tool will help to better define when erosion occurs, how it occurs, and also how and when coating occurs.

UNCURED END BURNER DEVELOPMENT

Because JPL cannot process or test beryllium propellant in their own facilities, a JPL-540 type propellant with a higher aluminum content is being developed to use for simulation of the flame temperature of a berylliumized propellant. To evaluate rocket inert materials with this propellant, at reasonably high chamber pressures and long burning times, an end burner concept is feasible. The following requirements were used in the design of the motor:

1. Chamber pressure, 400 to 800 psia.

2. Burning time, 100+ sec.

3. Minimum throat diameter, 1.0 in.

It is not feasible to test a large diameter end burner of cured propellant because of the extreme internal stresses causing cracks in the propellant. Therefore, it was decided to use the JPL-540 type propellant in an uncured condition.

A 12-in. diameter chamber has been fabricated that will allow testing of a 1.0-in. throat diameter at 500 psi for approximately 30 sec. Figure 3 shows a schematic of this chamber.

This chamber will be used to develop a design for any larger chamber required, and also will serve as a screening tool for candidate materials. The chamber was designed so that chamber insulation, aft closure insulation, and nozzle materials can be tested at the same time.

Small 35-lb batches of propellant have been made to develop the required formulation. Preliminary tests have been made with small 5 x 6 chambers, primarily to evaluate ignition methods. A hot-wire igniter, with a small piece of cured propellant, laid on the surface of the propellant proved quite successful for ignition.

Future Activities

It is planned to begin testing with the 12-in.-diameter chamber some time in August. Design of the larger chamber should begin in October, with fabrication starting the first part of November.

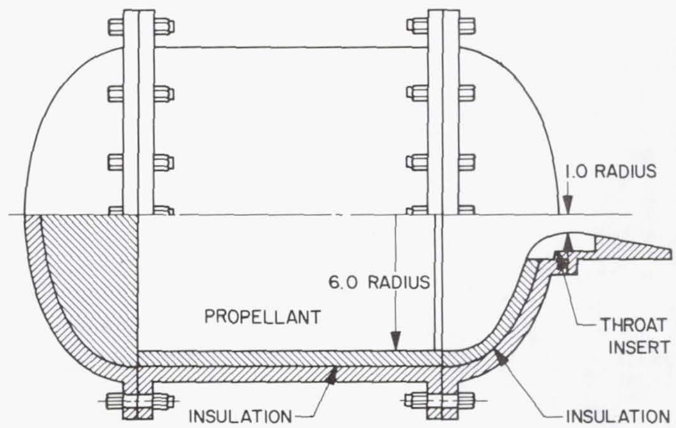


Fig. 3. Uncured propellant end burner

Page Intentionally Left Blank

HIGH-ENERGY SOLID PROPELLANT DEVELOPMENT
NASA Work Unit 128-32-05-01
JPL 328-21001-2-3810

IN-HOUSE DEVELOPMENT

High-Energy Solid Propellant Containing Uncoated NP

A thermoplastic, rubbery binder compatible with NP was developed. It consists of a mixture of a special grade of polyethylene (copolymer with vinyl acetate) and refinery asphalt plasticized with refinery flux oil or heavy kerosene. Theoretical performance calculations predict a specific impulse a few seconds higher than the model $(CH_2)_n$ binder and a small reduction in NP content to attain maximum performance. A practical method of processing needs yet to be developed because of the low decomposition temperature of NP (140°F). Two methods have been demonstrated that have severe limitations. The first method uses a volatile solvent (such as hexane) that must later be removed by evaporation, a slow process resulting in considerable shrinkage. The second method depends on incorporation of sufficient plasticizer to reduce the binder melting point to below the decomposition temperature of NP. Such a propellant would have to be stored at temperatures below 40°F. These methods will be subjected to further investigation as will others, such as cross-linking the low-melting binder and low-temperature plastisol cure of higher melting compositions.

HP_2 Propellant Development

A characterization study of hydrazine diperchlorate has been going on for some time with the end objective of developing a high performance propellant system based on HP_2 as the oxidizer. A rather thorough study is being made of the HP_2 about its chemical and physical properties and, also, its safety and handling properties. The analytical techniques required for chemical analysis have been developed and several samples from each of the three different lots of HP_2 now on hand have been analyzed. The purity of the three lots range from approximately 95.5 to 97.5% HP_2.

The sensitivity to impact and the effects of impurities and residual solvents on sensitivity have been determined. HP_2 is somewhat more sensitive to impact than ammonium perchlorate but nevertheless it is in a sufficiently reasonable range to not pose a major problem in handling. A much greater problem is that of moisture. HP_2 is very hygroscopic and, therefore, must be handled in a carefully controlled atmosphere. A study of the tolerable moisture limits for proper handling and the effects of moisture on the properties of HP_2 is under way. Preliminary data indicates that slightly less than 0.5% may be tolerable. Exposure to a moist atmosphere, however, tends to make the HP_2 less sensitive to impact.

A considerable amount of incompatibility exists between the HP_2 and potential binder ingredients, a problem that complicates the propellant development effort. However, some success has been experienced in the attempt to eliminate this incompatibility. Efforts are continuing to develop a compatible system.

Boron Propellant

A single small batch (ca. 10 gm) of B-N-H propellant (BI-2, PEH, hydrazine) was prepared in glassware to check for process problems arising out of the use of ingredients long in storage and known to be unstable. The batch was intended as a preliminary to the preparation of larger batches in the small mixer facility now completed. The benchtop operation did not reveal any new problems, but did emphasize the need for the process controls that are built into the small mixer facility. The experiment led to information about physical properties, case bonding, impact sensitivity, and thermal stability of the propellant; but the findings cannot be considered representative, considering the process limitations. It was concluded that heating of strand molds will be necessary during casting just as has been arranged for the casting of motors. Propellant processing in the 1-pint mixer is now beginning. Characterization and development of the B-N-H propellant will proceed during the next report period.

OUT-OF-HOUSE RESEARCH AND DEVELOPMENT

LMH-2 Product Improvement

Contract number 950894 with the Ethyl Corporation, Baton Rouge, La., begun October 1964, calls for the development of improvements in synthesis and purification leading to LMH-2 with higher density and purity. Several months of effort with the specified approach showed no promise: purities ranged from 57.5 to 97.7%; density was not improved, and no significant degree of crystallinity was observed. Because of the specific nature of the work statement, stop-work and negotiation to write a modified contract directing Ethyl to use different synthesis approaches was necessary. Three mo. were lost in these procedures. Work was resumed recently, but no results are available at this time.

Polymeric Binder for Advanced Solid Propellant and Hybrid Solid Grains

A request for proposal, no. 1210, for the above work was prepared and mailed to 15 companies. The request describes the binder as follows: (1) the binder should be compatible with uncoated, highly acidic oxidizers, (2) the binder should be suitable for hybrid solid grain, (3) the binder when mixed with NH_4ClO_4 to form solid propellant should withstand sterilization by heat (293°F), and (4) the binder when mixed with NH_4ClO_4 to form solid propellant should withstand the environment of space; i.e., temperature range, vacuum, and nuclear radiation. Bids have been received from five major companies: Aerojet-Sacramento, Dow Chemical Corporation, Rocketdyne, Shell Chemical Company, and Union Carbide Corporation. Bids have been evaluated, and negotiations are now in progress. In the next reporting period, management of the contract with one of the successful bidders and the evaluation of samples at JPL will be conducted.

FACILITIES, EQUIPMENT, SERVICES

A completely remotely-operated 1-pint propellant mixer station has been completed and has just been put into operation. It is designed so that, from the time loaded hoppers are attached to the mixer until propellant is cast and cured, no person will enter the processing cell. To meet the requirements of a variety of energetic chemicals, the station includes separate, sophisticated atmosphere and temperature controls for several distinct operating elements. See Fig. 1 for views of mixer and remote-control panel.

A remote-loading thrust stand for testing motors with small grains (up to one pound) of high-energy propellants has been completed and tested. The stand is expected to accommodate thrusts from 50 to 500 lb with durations as low as 0.1 sec.

An apparatus for determining the sensitivity of chemicals and propellant mixtures to static electric discharge has been built under contract. It awaits testing.

A Perkin-Elmer differential scanning calorimeter has been purchased. It is being used to obtain thermograms of high energy oxidizers and other materials.

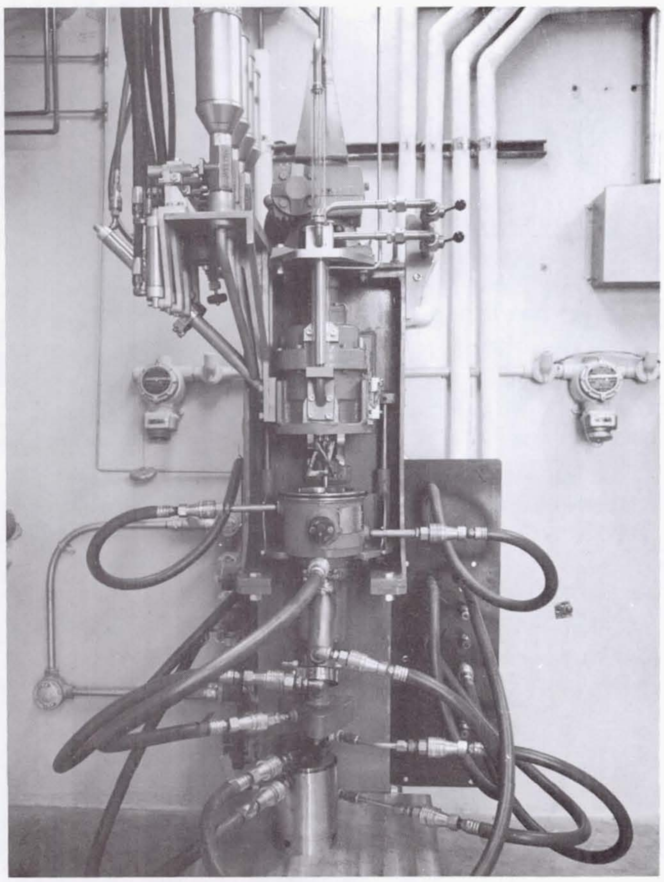


Fig. 1a. One-pint propellant mixer station (Mixer)

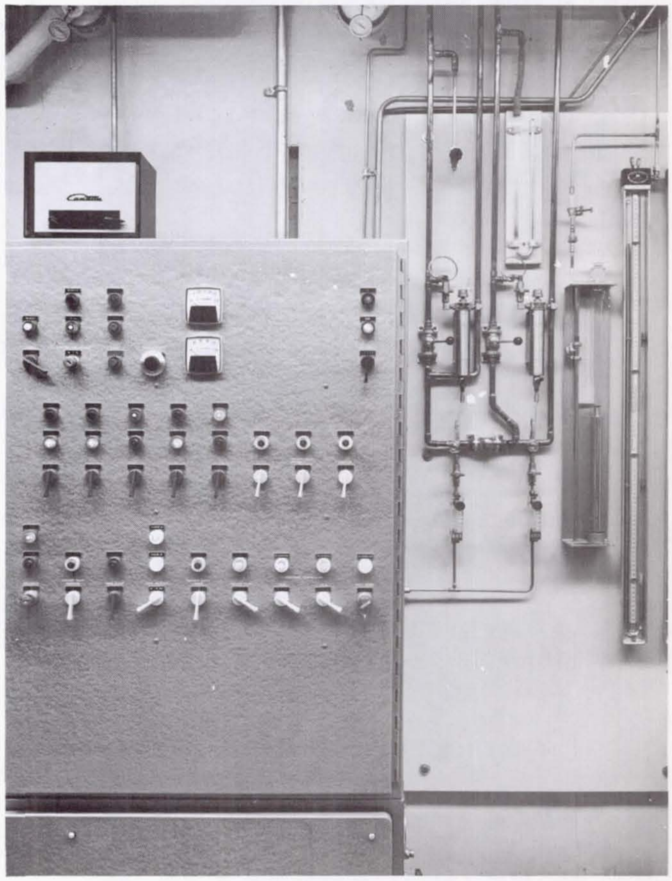


Fig. 1b. One-pint propellant mixer station (Remote control panel)

Design and procurement activities are now going on to convert a test cell to a remote, controlled-atmosphere laboratory for exploratory studies involving sensitive or uncharacterized high-energy chemicals. Master slave manipulators will be used.

Technical support in the area of quality control and characterization of high-energy propellant ingredients is being provided by means of two contracts. Such work with HP_2 is being conducted by Aerospace Chemical Systems, Inc., Gardena, California, contract no. 951126. The analysis and testing of the boron propellant ingredients is being done by Dynamic Science Corporation, South Pasadena, California (Purchase Order CN5-356148).

JPL solid propellant processing and testing facilities are being reviewed by experts of the Atlantic Research Corporation, Alexandria, Virginia, for their adaptability to use in the study of toxic beryllium propellants. The final product of this study will include design recommendations to provide toxic-safe conditions for such work (Purchase Order DH5-366270).

The Laboratory recently obtained an IBM 7090 program for computing rocket propellant performance. Known as "The Lewis Program," it was written by Gordon and Selenik of the NASA Lewis Research Center. Cooperative effort by personnel of several sections has provided a modification of the program to integrate JANAF thermochemical data into the program and for easy substitution of revised and new data in the future.

CONFERENCES

ICRPG 21st Interagency Solid Propulsion Meeting; June 9-11, 1965, San Francisco.

Specialist Session; Solid Propellants Containing Beryllium, participants: F. A. Anderson, and J. F. Newton, Jr.

Specialist Session; Mechanisms of Cure Reaction, participant: H. E. Marsh, Jr.

ICRPG Ad Hoc Study Group on Chemical Rocket Propulsion; Steering Committee Member: F. A. Anderson. Systems Requirements Sub Group Members: W. Gin, H. E. Marsh, Jr.

AIAA Solid Rocket Conference; Feb 1-3, 1965, Washington, D. C., Paper presented: Sterilized Solid-Propellant Rocket Motors for Mars Landing Missions, L. C. Montgomery and H. E. Marsh, Jr.

ACS/AIAA Symposium on Advanced Propellant Chemistry; April 6-7, 1965, Detroit. Attendees: F. A. Anderson, N. Zimmerman.

PUBLICATIONS

Space Programs Summary (SPS)
Volume V - Supporting Research and Advanced Development (Confidential):

SPS No. 37-31, December 1, 1964 to January 31, 1965, Development of High-Energy Solid Propellant, F. A. Anderson (Confidential).

SPS No. 37-32, February 1, 1965 to March 31, 1965, Development of High-Energy Solid Propellant Containing NO_2ClO_4, F. J. Hendel (Confidential).

Technical Report No. 32-725, Sterilized Solid-Propellant Rocket Motors for Mars Landing Missions, March 30, 1965, L. C. Montgomery and H. E. Marsh, Jr., (Confidential).

Paper for presentation at the XVIth International Astronautical Congress, September 1965, Athens, Greece, Review of Solid Propellants for Space Exploration, F. J. Hendel.

Page Intentionally Left Blank

RHEOLOGICAL PROPERTIES OF PROPELLANTS
NASA Work Unit 128-32-05-02
JPL 328-20301-1-3820

ULTIMATE PROPERITES IN UNIAXIAL TENSION

It has been determined experimentally that failure data for a wide variety of elastomeric systems can be represented by a stress-strain law derived from the kinetic theory of rubberlike elasticity, modified to account for the limited extensibility of the rubber network. The equation is:

$$\frac{3\sigma_b}{\nu_e RTn^{1/2}} = \mathcal{L}^{-1}\left(\frac{\lambda_b}{n^{1/2}}\right) - \frac{1}{\lambda_b^{3/2}}\mathcal{L}^{-1}\left(\frac{1}{\lambda_b^{1/2} n^{1/2}}\right) \tag{1}$$

where

σ_b is the stress-at-break based on the initial cross-sectional area

ν_e is the concentration of network chains per unit volume of whole rubber

λ_b is the extension ratio-at-break

n is the number of statistical units or freely orienting units per chain

$\mathcal{L}^{-1}$ is the inverse Langevin function.

CARBOXYLIC RUBBER

Hycar 1072 is a polymer of acrylonitrile and butadiene containing a few percent of free carboxylic acid groups. When vulcanized with a material such as zinc oxide, which forms ionic cross-links, the elastomer appears to be "self-reinforcing" because the tensile strength is very high even in the absence of crystallization or highly reinforcing carbon black filler. On the other hand, when covalent cross-links are present, the strength is much reduced; in some instances as much as by factors of 20 to 50. To determine a possible mechanism for this "self-reinforcing" phenomenon, the uniaxial stress-strain properties of Hycar 1072 containing (1) ionic cross-links, (2) covalent cross-links, and (3) mixture of ionic and covalent cross-links, will be obtained as a function of rate and temperature.

FOAMS

Foamed elastomers, as analogs of the highly filled propellants, are also being investigated. An effort is now being made to obtain stress-strain data that are independent of the specimen geometry. It appears that for strains greater than about 20% this can be done by using ring specimens because the data from rings and data obtained photographically, using dumbbell-shaped specimens, agree when the strain

is greater than about 20%. Swelling experiments are now under way that should enable us to determine the best solvent and swelling conditions for specimen characterization.

RHEOLOGY OF SLURRIES

Our primary concern over the last 6 mo has been a study that has shown that one of the primary mechanisms, which determine ϕ_m (sedimentation volume) and, therefore, the relative viscosity of slurries through the apparent Newtonian region, is a particle-to-particle interaction. This interaction is completely independent of the suspending medium for the particle sizes studied thus far. It further appears that for each material, e.g., glass, aluminum, copper, etc., there is a master curve relating ϕ_m to particle size, though this curve is sensitive to the particle size distribution. For the purposes of this study, the curve has been separated into three distinct regions: the region where the ratio of surface force to body force is very small; the transition region where the ratio is intermediate and where most previous work on the viscosities of slurries has been concentrated; and the region where the ratio is large and surface phenomena dominate the behavior (Fig. 1). The surface phenomenon of interest is the particle-to-particle attractive force arising from London-van der Waals attractive forces. In this study, the relative attractive forces are expressed as a function of the parameter ϕ_m. The effect of particle size and mixtures of different types of particles on ϕ_m have been handled in terms of probability analysis. Work is continuing on this problem and a paper on the subject has been accepted by the ICRPG for presentation in San Diego in November.

BURNING RATES

A program on the effects of the decomposition of the oxidizer on the burning rate of composite solid propellant is now under study. It has been found that the temperature at which either the predecomposition or the major decomposition of ammonium perchlorate occurs can be changed by surface treatment of the perchlorate and that these changes are reflected in the burning rate of the propellant. For

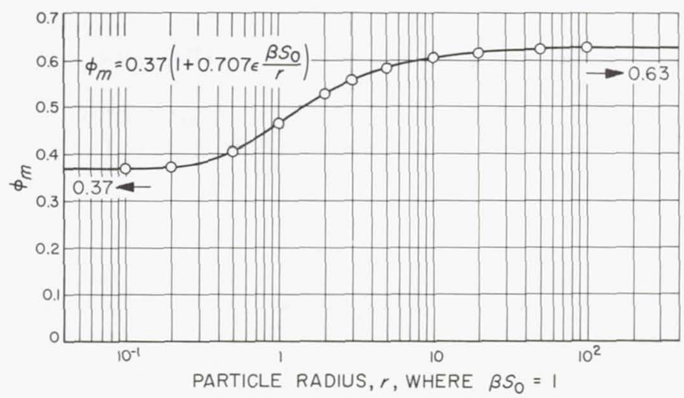


Fig. 1. Generalized ϕ_m for a uniform group of spheres of $BS_o = 1$ for infinitely large container

example, an effective surfactant shifts the 29% decomposition peak to a higher temperature and results in a slower burning rate; on the other hand, copper chromate, magnesium oxide, or copper chloride shift the predecomposition and the major decomposition to lower temperatures and produce faster burning rates. A paper will be written on this subject within the next 3 mo.

CONTRACTS

The contract with American Potash and Chemical, Inc. has expired. The work done confirmed our expectations for the relationship between the decomposition as observed by differential thermal analysis and the burning rate (holding particle size and degree of dispersion constant). The contract with Astropower, a division of Douglas Aircraft, is proving most interesting because the surface area measurements that they are providing on our particles also include a parameter that can be correlated with the heats of adsorption. The latter is, in turn, directly related to the surface energy of our particles and therefore with ϕ_m; hence, with the viscosity of slurries and the modulus of cured systems. Calculations are being made and will be presented in a paper for the November meeting of the ICRPG Working Group on the Mechanical Properties of Solid Propellants.

FINITE DEFORMATION OF ELASTOMERS

Experimental work has been completed on the second in the series of materials to be studied in the program to determine the parameters that affect the form of the strain energy function, W, of elastomers. This second material is Silastic 950 u, a polydimethyl siloxane containing 28 weight % silicon dioxide filler. Like natural rubber, the Silastic 950 u was found within experimental error to be incompressible, its strain energy function was therefore taken to depend only on the strain invariants I_1 and I_2. The gradients of the strain energy function for these invariants of the strain, designated as W_1 and W_2, were experimentally evaluated. Whereas, for natural rubber W_1 is reasonably constant, the value of W_1 for the silicon rubber was found to increase linearly with I_1. The dependence of W_2 on the invariants is similar to that found for natural rubber and it was found that W_2 is a strong decreasing function of I_2. Though it is obscured because of the coupling between I_1 and I_2, apparently W_1 and W_2 are respectively independent of I_2 and I_1.

A function derived from the data is in the form

$$W = A_1 (I_1 - 3) + A_2 (I_1 - 3)^2 + A_3 (I_2 - 3) + A_4 (I_2 - 3)^2 + - - - A_n (I_2 - 3)^n$$

This form may be compared with the two-constant form proposed by Mooney

$$W = C_1 (I_1 - 3) + C_2 (I_2 - 3)$$

The origin of the terms involving invariants to powers higher than the first, seen in the strain energy function of Silastic 950 u, is now unknown. Further work is being carried out to determine the roles of filler, cure conditions, nature of the polymer chains, and molecular parameters on the complexity of the strain energy function.

PAPERS

Some Effects of Fillers on the Deformation and Rupture of an Elastomer, by R. F. Landel.

Society of Rheology Winter Meeting, January 28-29, 1965, Santa Barbara, California, An Apparatus for Biaxial Stress-Relaxation Measurements of Rubberlike Materials under Large, Combined Torsion and Tension, by G. W. Becker, J. M. Kendall, Sr., P. A. Caruthers, and R. F. Landel.

Winter Meeting of the Gordon Research Conference, Santa Barbara, California, February 1-5, 1965, Tensile Rupture in Amorphous Elastomers, R. F. Landel and R. F. Fedors.

DEGRADATION MECHANISMS
NASA Work Unit 128-32-05-03
JPL 328-20401-1-3820

TRACER METHODS FOR STUDYING DEGRADATION MECHANISMS OF POLYMERS

The objective of this work unit is to investigate the molecular structure, chemistry, and degradation mechanisms of polymeric materials. Because relatively large changes in mechanical properties can result from small chemical changes that occur in the early stages of polymer degradation, sensitive means of observing chemical changes (e.g., bond scission), are required. One method of this type is to incorporate C^{14} into the polymer chains at linkages that will be involved in the degradation reactions and to then monitor a C^{14} labeled product. For the urethanes being studied here, it is known that the urethane linkage undergoes some scission to evolve carbon dioxide. Therefore, studies of the thermal degradation at moderate temperatures (109, 128, and 150°C) of poly (propylene oxide:PPO) reacted with C^{14}-labeled p-tolyl isocyanate are in progress, as well as studies of the determination of the reactive end-group molecular structure of PPO discussed below.

Measurements at 128 and 150° C showed nearly the same linear rate of $C^{14}0_2$ evolution, compared with a substantially lower rate at 109°C. Because the temperature dependence should give more nearly constant activation energies than these results indicate, an additional run is being made at >128°C to check the previous rates and experiments at lower temperatures (<108°C) are being started. (The lower temperatures are of greatest interest because they are more characteristic of environmental aging.) None of the experiments completed to date have indicated measurable changes in infrared spectra or intrinsic viscosities of the residual polymer. These results are consistent with exclusive urethane scission. Future studies will include similar experiments with the cooresponding o-tolyl isocyanate adduct to compare the scission rates of urethane groups in the 2- and 4-positions. Tentatively, it is planned to let a small outside contract (probably with an academic institution) to examine the feasibility and, if reasonable, to construct an apparatus for simultaneous measurement for crosslinked urethanes of $C^{14}\,0_2$ evolution, mechanical properties, and/or wide-line nuclear magnetic resonance spectra, so that changes in molecular structure can be correlated with $C^{14}\,0_2$ evolution. A work statement is being prepared now.

NUCLEAR MAGNETIC RESONANCE OF POLY (ALKYLENE OXIDES)

Because the reactive terminal structure of PPO, or other polymers, may determine the mechanism of degradation (or chain extension), the end group molecular structure of PPO has been determined by nuclear magnetic resonance (n.m.r.). The H^1 and F^{19} spectra of acetates and trifluoroacetates of PPO and other model diols have been examined in these studies. Because fluorine derivatives produce greatly accentuated chemical shifts, very subtle structural differences have been detected. In addition to demonstrating the simple determination of the relative concentrations of primary and secondary hydroxyl groups in mixtures of hydroxy compounds, F^{19} n.m.r. was used to establish stereo and positional isomeric configuration of the terminal and next adjacent monomeric units in PPO and poly (ethylene oxide-propylene oxide) copolymer. Atactic PPO contains nearly equal

concentrations of syndiotactic and isotatic diols at both ends of the polymer chains, showing only a minor amount of stereoselectivity; whereas poly [(+) 1-propylene oxide] contains only one of the two possible relative stereoconfigurations of the terminal neighboring asymmetric carbon atoms at the chain ends. This result can be seen in Fig. 1, in which the secondary trifluoroacetate n. m. r. signal is a doublet for atactic PPO and is a singlet for poly [(+) 1-propylene oxide.] Separate n. m. r. measurements for mixtures of the ditrifluoroacetates have established that the singlet represents one member of the doublet. Ditrifluoroacetates of poly (ethylene oxide-propylene oxide) prepared by further addition polymerization of ethylene oxide to PPO produce different F^{19} chemical shifts depending on whether only one or more than one ethylene oxide unit is attached to the propylene oxide units. The approach described here suggests that even more detailed structural assignments can be established for poly (alkylene oxides), as well as for other polymers containing reactive terminal or pendant structures, by application of more advanced n. m. r. techniques. To assist with a continuing effort along these lines, Professor F. A. L. Anet of UCLA has been obtained as a consultant.

The most recent results on this work have been submitted for publication in the SPS and a complete paper has been written for presentation at the Canadian Meeting in September. It will also be given at the ACS Meeting in September.

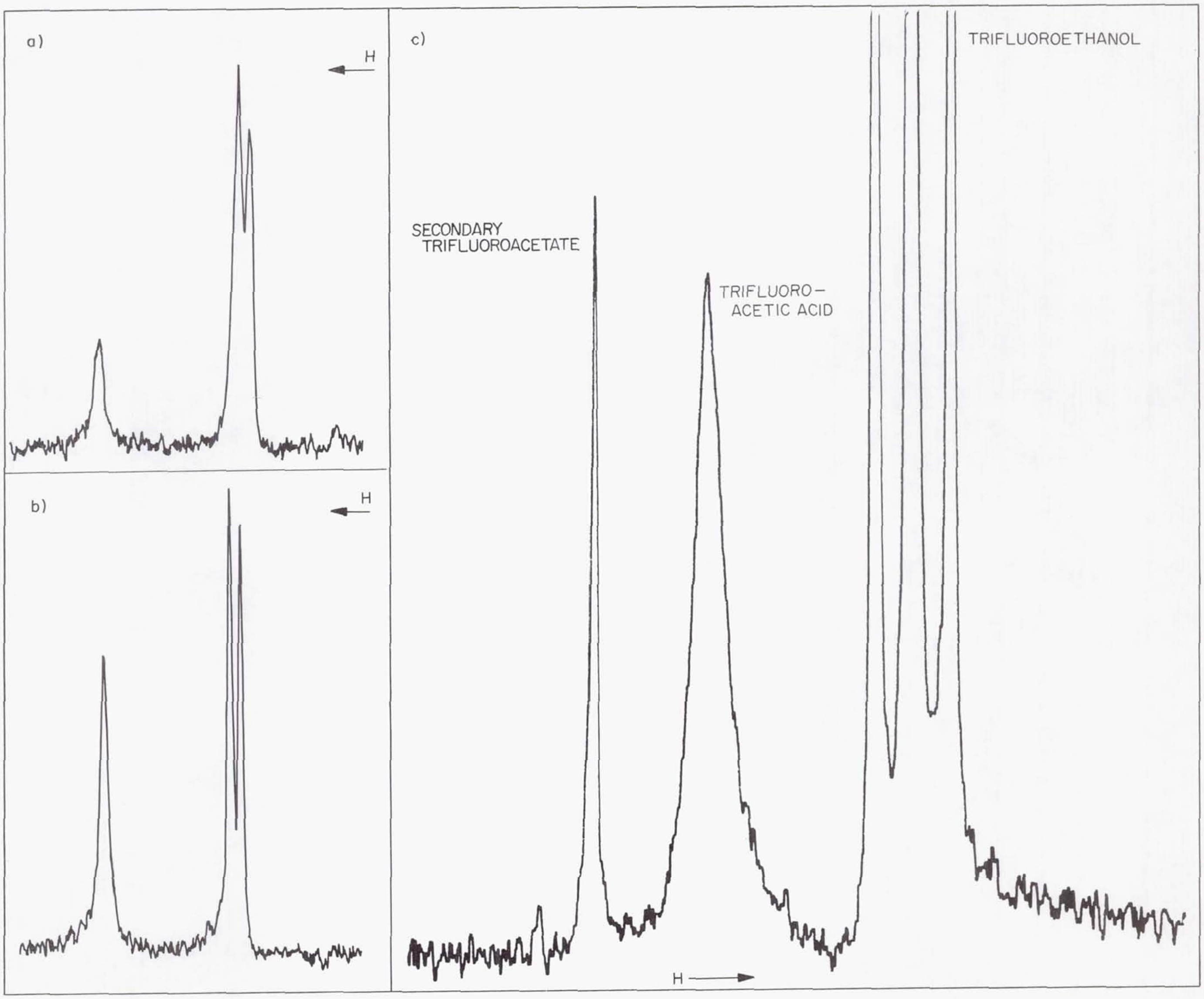


Fig. 1. F^{19} nuclear magnetic resonance spectra of ditrifluoroacetates at 56.4 Mc

a) Poly (propylene oxides) of molecular weight ~ 425

b) Poly (propylene oxides) of molecular weight ~ 2025

c) Poly [(+) 1-propylene oxide] in benzene

Page Intentionally Left Blank

PROPELLANT STRESS ANALYSIS STUDIES
NASA Work Unit 128-32-05-04
JPL 328-20501-1-3820

The propellant stress analysis studies program consists of a broad spectrum of activity including applied engineering, development, and pure research. The purpose of this program is to review the technology of theoretical and experimental stress analysis pertinent to solid propellant, as well as to maintain JPL's leadership in these fields (Ref. 1 to 9).

APPLIED ENGINEERING ACTIVITIES

A current task is to evaluate the reliability of state-of-the-art theoretical treatments now being used by industry. The approach to this task is to apply the unique experimental capabilities of JPL to a flight motor, such as the Surveyor retromotor. The discrepancy between experimentation and theory (mutually exclusive) will serve as the parameter to evaluate the reliability of theoretical state-of-the-art stress analysis solutions.

Experimental Aspects

Six 9-in. spherical thin walled motor cases (for analog motor testing) are under construction. Techniques are being developed to locate miniature stress rosettes (Ref. 1, 2, and 3) within a spherical propellant grain having a tapered seven point star port configuration. Thermocouples and metallic strain gage rosettes are also being used together with complementary instrumentation. Techniques are being developed for casting propellant and photoelastic stress freezing epoxy resin (exotherm problem) into the instrumented hardware. Production techniques are being established for the construction and calibration of some 90 stress transducers, e.g., Fig. 1 illustrates a chain loading device that enables direct tension-compression-temperature calibrations. Viscoelastic mechanical property data are also being obtained, as required, for aluminized AP/CTPB, AP/Polyurethane propellant, and photoelastic stress freezing epoxy resin for incorporation in the theoretical analysis. This experimental program will measure the stress-strain response of a general class flight type solid propellant motor for the temperature-time realm including casting, curing, and pressurization.

Theoretical Aspects

A contract (NAS 7392) has been awarded to the Douglas Missile Division to use an existing redundant force stress analysis computer program to analyze the 9-in. spherical motor over the same environmental regime used in the experimental portion of this program. Because this theoretical approach is independent of the analog motor experimentation, any discrepancies between experiment and theory can be reviewed to estimate the confidence level of structural integrity reliability predictions for solid propellant of all size classes.

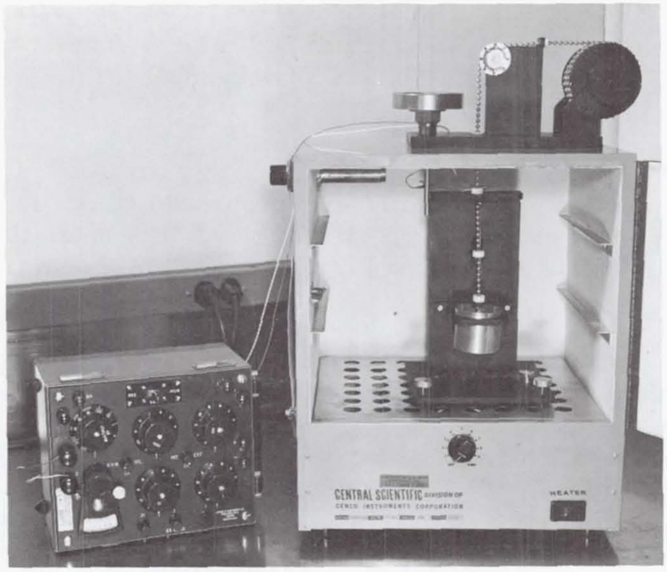


Fig. 1. Transducer stress-temperature calibration apparatus

DEVELOPMENT ACTIVITIES

The current tasks have been focused on instrumentation and transducer development, modification, and eventual simplification for industrial application (Ref. 4). Primary tasks are focused on the miniature stress transducer, photoelastic stress freezing, the biaxial sheet tester, and the viscoelastic polariscope.

Miniature Stress Transducer

The miniature stress transducer (0.050 X 0.050 in. diameter), Fig. 2, is being evaluated for practical applications. Problems being resolved (Ref. 5) are inclusions, the packaging function, temperature interaction, and whether stress or strain should be considered as the argument of the transducer output function.

Photoelastic Stress Freezing

Work is underway with Bakelite epoxy resins (condensation polymers of bisphenol and epichlorohydrin) to cast, machine, photograph, obtain optical and mechanical properties, and interpret the three-dimensional stress-strain-birefringence properties. One problem that has been looked into is the stress transducer and thermocouple inclusion effect (Fig. 3). An oven has been designed to obtain stress optical data as a function of temperature. Operation of this oven is expected in the near future. The epoxy material is used as the analog material to reference elastic theory and solid propellant grain stress analysis.

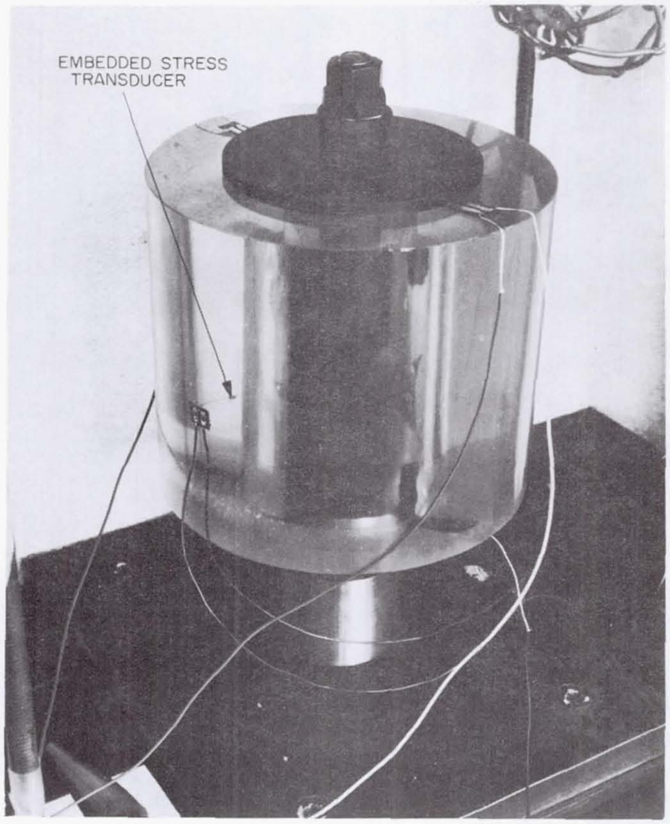


Fig. 2. Embedded stress transducer

Biaxial Sheet Tester (Ref. 6)

An optical oven has been designed to obtain biaxial physical properties of both photoelastic resins and solid propellant. Figure 4 illustrates a method of calibrating the stress state at the center of a 6- x 6- x 0.1-in. sheet for applied boundary loadings and displacements. In this figure photoelastic fringe patterns are shown in the vicinity of two orthogonally embedded stress transducers.

Viscoelastic Polariscope (Ref. 7)

An oven has been constructed that may be attached to the existing polariscope loading fixture. This capability enables multiaxial stress-strain-temperature-time measurements of cylindrical thick walled cylinders of stress freezing epoxy, unfilled binder, or solid propellant. Figure 5 illustrates techniques developed to incorporate miniature stress rosettes within cylindrical thick-walled cylinders (Ref. 8). These techniques together with the polariscope apparatus are easily modified to examine spherical motors.

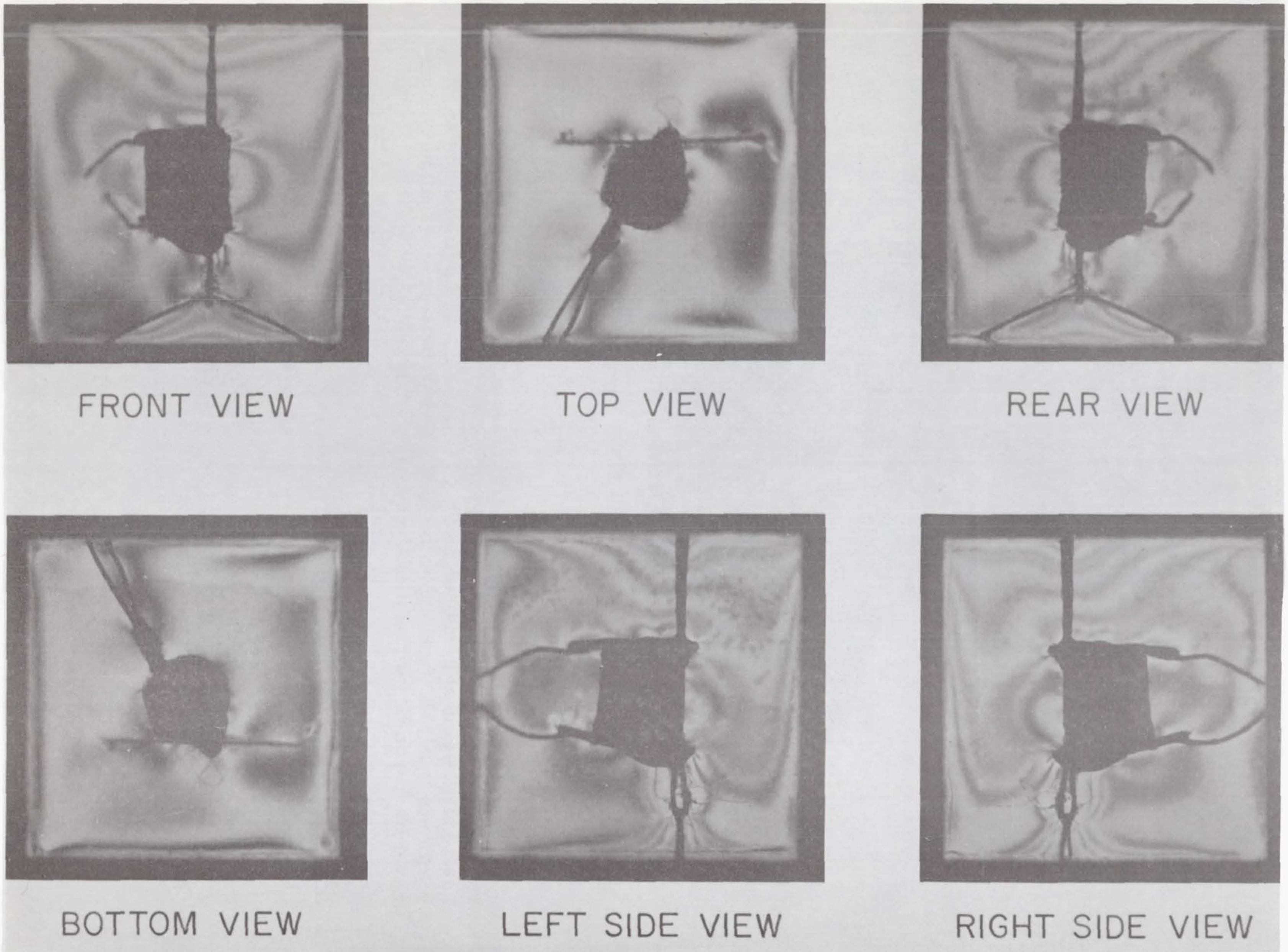


Fig. 3. Three-dimensional stess freezing phenomena

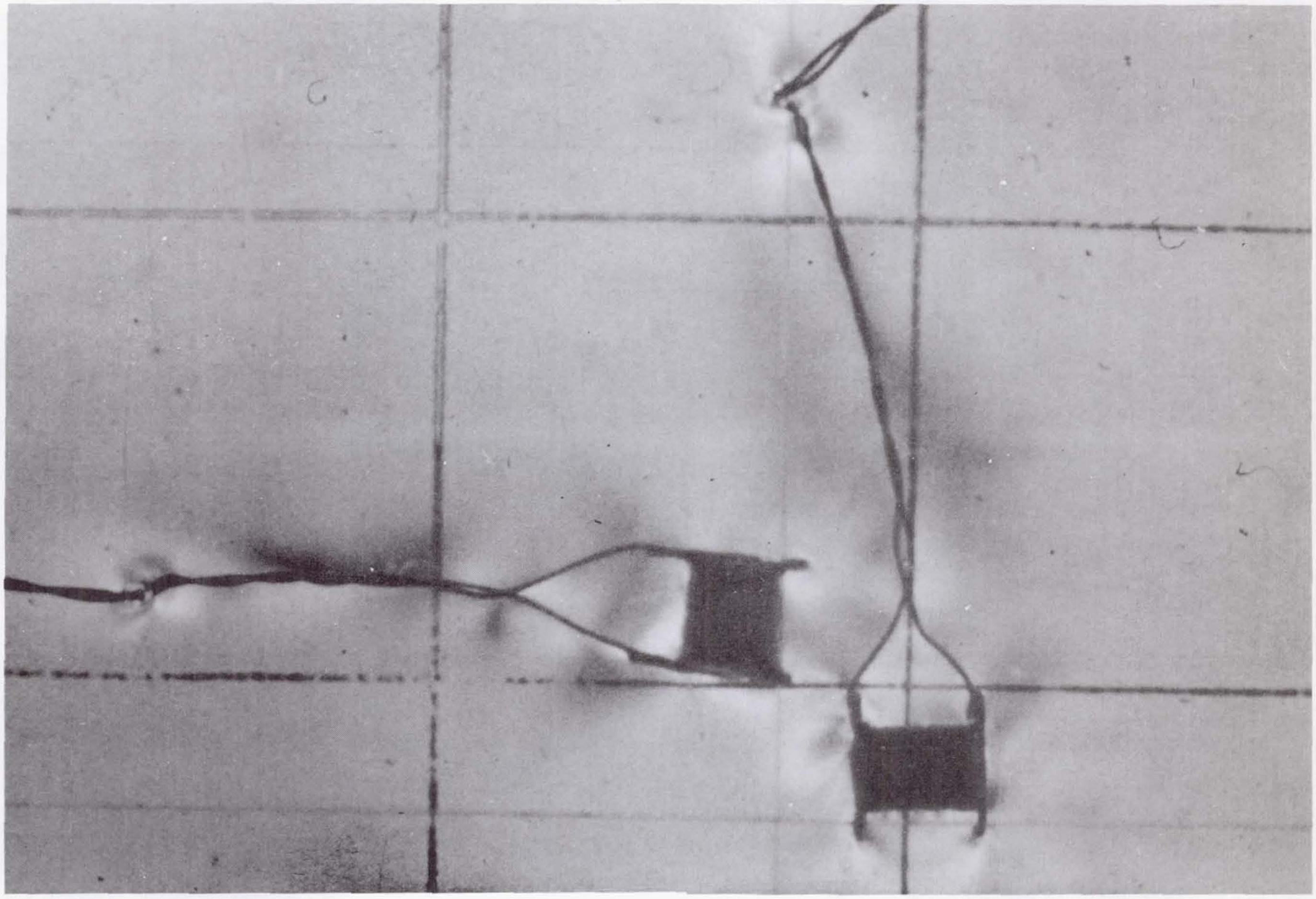


Fig. 4. Biaxial sheet experiment

RESEARCH ACTIVITIES

Current activity is centered on energy methods based on continuous media theory to characterize multiaxial mechanical properties, general stress analysis, and photoelastic stress freezing.

1. Penn State University is under contract to continue their multiaxial test program in conjunction with their analytical program, based on continuous media theory, to characterize the mechanical behavior of solid propellant motors. This work complements our in-house program in the same field. Results of experimental studies indicate that failure of some, if not most, solid propellants cannot be explained by criteria developed in metal technology. The concept of strain energy and dissipation energy is being investigated; however, no simple straightforward theory appears imminent. JPL supplied Penn State with several long thin-walled resin tubes for their participation in a joint test program. Results from these tests were compared to results obtained at JPL. Preliminary

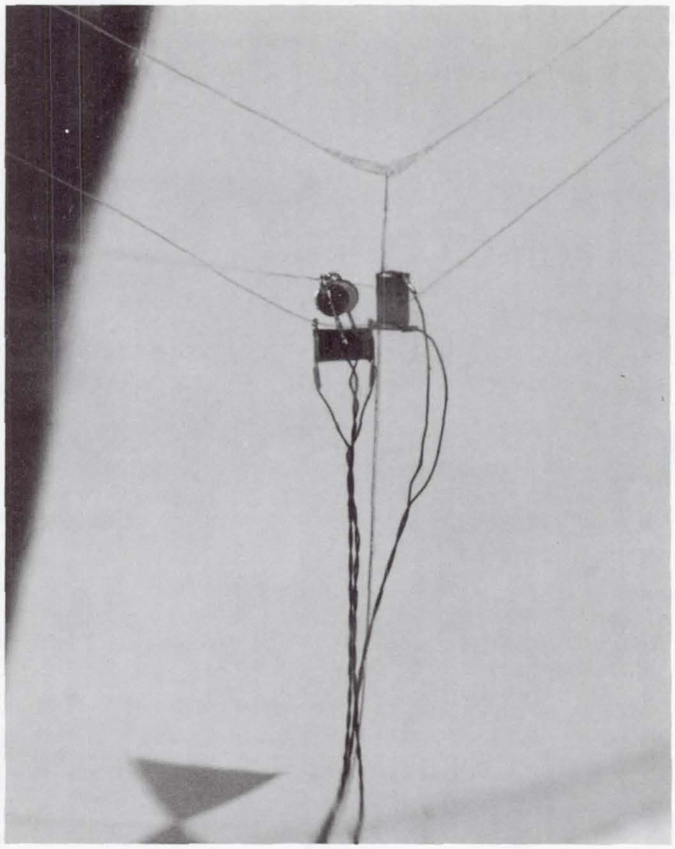


Fig. 5. Three-dimension stress rosette location and mounting development

analysis indicates that the experimental accuracy of experiments performed at Penn State can be improved, and modifications to do this have been suggested.

2. Theoretical studies at JPL have implied that the strain energy concept (and hence the memory concept) is difficult to develop in ordinary engineering nomenclature. The applicability of a general strain energy function concept to the stress analysis of solid propellant grains has not yet been demonstrated. Problems arise from experimental measurement difficulties; compressibility effects not included in contemporary forms of the general theory; dewetting phenomena and, hence, anisotropic phenomena; and finally the state-of-the-art inadequacy of linking molecular theory, homogeneous point stress analysis (mechanical properties), and macro structural response (applied stress analysis).

   A significant contribution to the better understanding of the strain energy function in the realm of small strain invariants (the realm experienced by solid propellant motors) has been made at JPL and unofficially confirmed (Ref. 9). It has been experimentally and theoretically shown that neither the Mooney nor the Mooney-Rivlin form of the universal strain energy function is applicable in the

small multidimensional strain realm. A paper is being prepared that will also include a convenient format to characterize multiaxial data in terms of the strain energy concept (Ref. 9).

3. Supplemental theoretical studies have been made in conjunction with transducer development. These studies include familiarity with the literature of piezoresistive semiconductors, special instrumentation, molecular interpretations of three dimensional photoelasticity, and a constant review of experimental and theoretical literature related to the stress analysis of solid propellants.

REFERENCES

1. San Miguel, A. and Silver, Robert H., On the Construction and Theory of a Miniature Stress Transducer to Measure Radial Stress in Propellant Grains, Technical Report No. 32-643, Jet Propulsion Laboratory, February 1965.

2. San Miguel, A. and Silver, R. H., Miniature Stress Transducer, Patent IR 30-591, Jet Propulsion Laboratory.

3. San Miguel, A. and Silver, R. H., "Radial Stress Measurements in Solid Propellant Grains," Bulletin of the Third Meeting of ICRPG Working Group on Mechanical Behavior, November 15, 1964, SPIA, The Johns Hopkins University, Applied Physics Laboratory, Silver Spring, Maryland.

4. NASA-JPL 609 (Movie) "Structural Integrity of Solid Propellant Rockets," Jet Propulsion Laboratory, March 15, 1965 (10.5 min.).

5. San Miguel, A. and Silver, R. H., Some Characteristics of a Miniature Stress Transducer, Space Programs Summary 37-33, Vol. IV, Jet Propulsion Laboratory, June 1965.

6. San Miguel, A., "A Biaxial Tester," Bulletin of the Third Meeting of ICRPG Working Group of Mechanical Behavior, November 15, 1965, SPIA, The Johns Hopkins University, Applied Physics Laboratory, Silver Spring, Maryland.

7. San Miguel, A. and Silver, R. H., "A Normal-Incidence Reflective Polariscope for Viscoelasticity Measurements," to be published in Experimental Mechanics.

8. San Miguel, A., Silver, R. H., and E. N. Duran, On the Practical Application of a Miniature Stress Rosette to Solid Propellant Grain Design, (to be presented to the ICRPG working group on mechanical behavior).

9. San Miguel, A., On the Characterization of Multiaxial Data in Terms of the Strain Energy Concept, (to be presented to the ICRPG working group on mechanical behavior).

Page Intentionally Left Blank

MECHANICAL PROPERTIES
NASA Work Unit 128-32-05-06
JPL 328-20701-1-3820

The Mechanical Properties program involves the study of the behavior of solid propellant grains in representative motor configurations under simulated operational environments.

In past testing with the strain-test motor chamber, it was concluded that the behavior of the grain, when pressurized under test conditions, approximated that of an ideal incompressible material. The test conditions provided radii ratios up to 10 and slow to moderate dP/dt.

In this reporting period, the equipment was modified to permit the use of larger radii ratios and to bring about the realization of pressurization rates in the category consistent with ignition shock rates. It is believed that the higher dP/dt will permit the attainment of peak strains without the significant perturbations caused by the normal binder retardation times.

Page Intentionally Left Blank

SOLID PROPELLANT GAS DYNAMICS PROGRAM
NASA Work Unit 128-32-06-01
JPL 328-21101-2-3810

LOW-PRESSURE COMBUSTION AND LOW-PRESSURE EXTINCTION

In earlier experimental studies with polyurethane-type composite propellants, the results indicated that the extinction pressure, while independent of the burning geometry, was strongly dependent on motor L* and certain other parameters such as the aluminum concentration in the propellant. With increased concentration of aluminum in the propellant, the slope of the L* versus extinction pressure relationship became steeper. When coarser aluminum was substituted in the propellant, the effect was to cause incomplete combustion at the low pressures, and the slope of the relationship and burning characteristics showed a trend approaching those of nonaluminized propellant.

Additonal studies were conducted to determine the effect of oxidizer particle size and binder system on the L* vs extinction pressure relationship. For the evaluation of the oxidizer particle size effect, two propellant formulations were used, both having the same percentage aluminum (Al), ammonium perchlorate (AP), and binder in the propellant. One formulation had a unimodal AP distribution with an average particle size of approximately 400μ (+48 mesh) and an average Al particle size of approximately 7μ. The other formulation had a bimodal AP (70/30) distribution (unground 400μ, ground 17μ) and with Al particle size of approximately 31μ. Burning rate data for these formulations in the low-pressure region were obtained by using the Crawford bomb strand burner. These data, along with JPL 540 propellant used in the earlier studies, are shown in Fig. 1. The formulation with the fine Al particle size, but with the coarser unimodal AP particle size distribution, suppressed the burning rate as expected, because of reduced packing density. However, it was interesting to find that the other formulation with the coarser oxidizer particle size, but also with the coarser Al particle size, resulted in a higher burning rate than the JPL 540 propellant.

For low pressure extinction tests, regressive burning 2-1/2-in. diameter and 4- and 4 1/2-in. along cylindrical charges were used in the 3-in. internal diameter test motor. With the standard squib-pellet system, these modified propellants could not be ignited either under vacuum or atmospheric firing conditions. Finally, satisfactory ignition was obtained by attaching strips of a different easily ignitable propellant to these charges. The results of the tests for the evaluation of coarser oxidizer particle size in propellant are shown in Fig. 2. The pertinent conclusion that can be drawn is that the slope of the L* vs extinction pressure relationship is not affected by the variation of oxidizer particle size in the propellant, and the variation in extinction pressure at a given L* is small.

Similar studies were conducted to evaluate the effect of binder system on the L* correlation. The formulation investigated contained polybutadiene-acrylic-acid binder system with 16% Al and an average Al particle size of approximately 28μ.

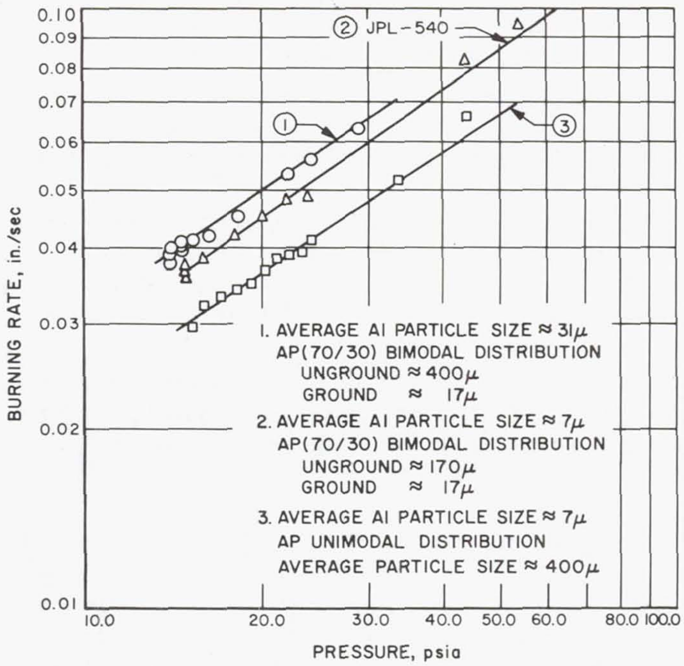


Fig. 1. Burning rate-pressure relationship; 16% Al in propellant

This formulation had AP (70/30) bimodal distribution. The results of the tests are shown in Fig. 3 along with modified JPL 540 propellant, which had approximately the same concentration and particle size of Al and AP in the propellant but used polyurethane binder system. As the results indicate, the slope of the L* correlation is not affected by the variation in binder system and the variation in extinction pressure at a given L* is quite small.

Additional studies will be conducted with nitroplastisol propellant, which was recently received from Lockheed Propulsion Company, and UTC propellant, which has not yet been received.

A program has been initiated to determine the effect of reduced pressure and variation in residence time on the performance of aluminized propellants. Propellants are now being processed for these studies.

ARC IMAGING FURNACE IGNITION TEST FACILITY

The arc imaging furnace ignition test facility, shown in Fig. 4, has become operational and has been used in two test programs. Early in the use of the system it was decided that the original Midwestern recorder would not be adequate for our needs. The results of a test run needed to be evaluated before the succeeding test could be planned and conducted. This necessitated a recorder with a light-sensitive print out. All instrumentation lines were therefore wired into the adjacent instrumentation room dynamics amplifier (Consolidated Electrodynamics Corporation recorder system). Figure 5 is a reproduction of the CEC oscillograph trace for an ignition test. The shutter photo diode records the duration of irradiation of the

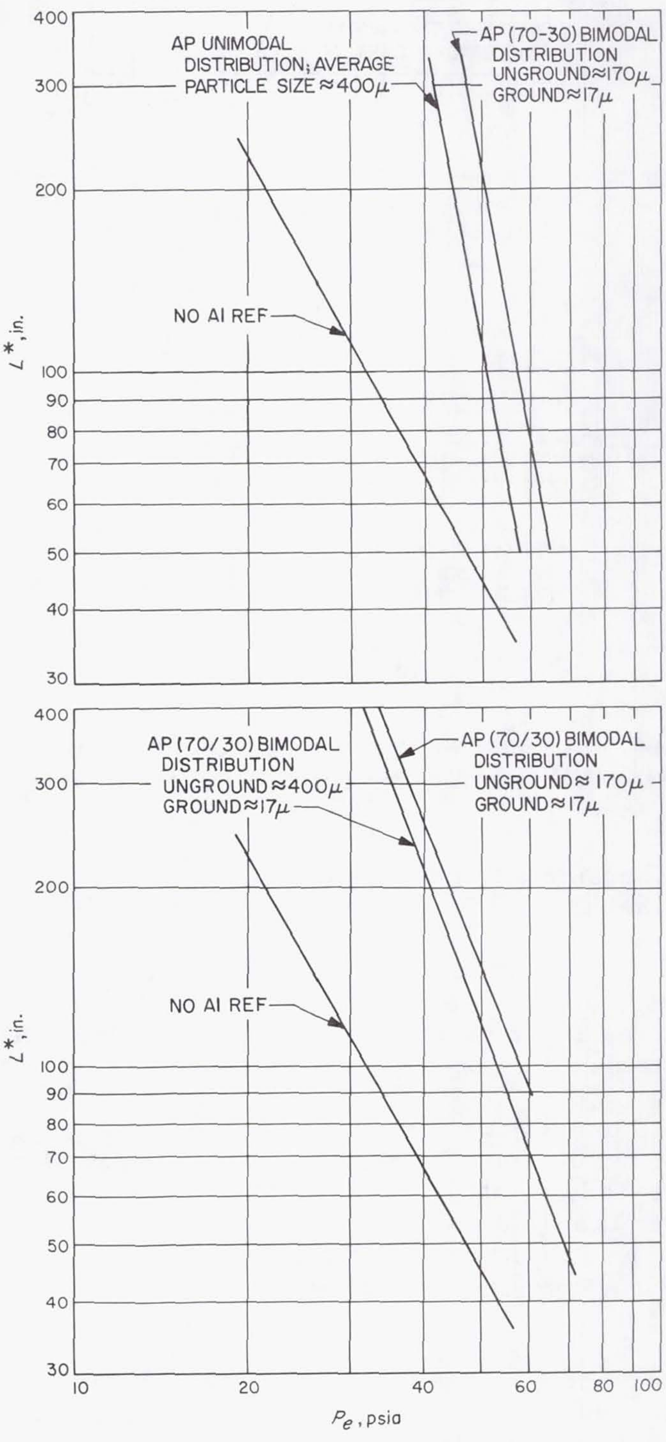


Fig. 2. Effect of AP particle size on L* vs extinction pressure relationship (Motor diameter = 3 in., temperature = 80°F, 16% Al in propellant)

a) Average Al particle size ≈7μ　　b) Average Al particle size ≈31μ

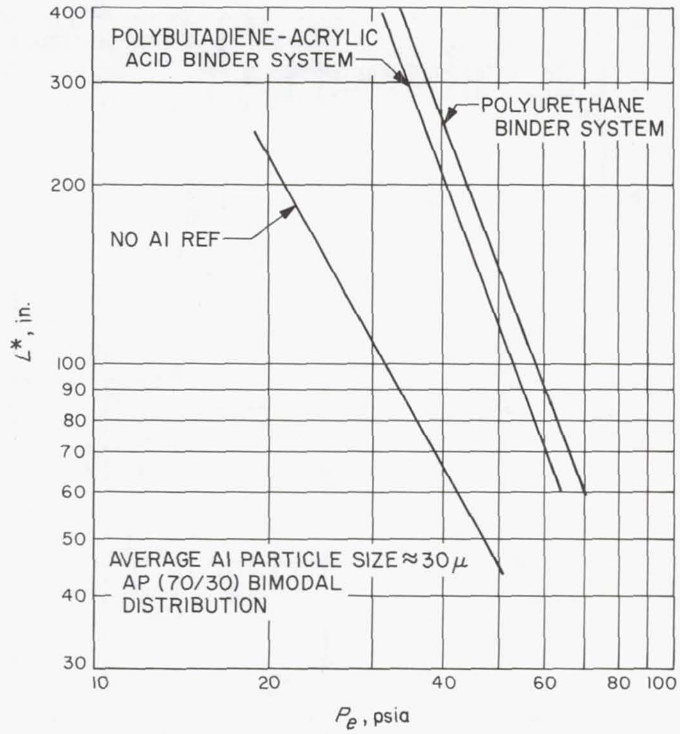


Fig. 3. Effect of binder system on L* vs extinction pressure relationship (Motor diameter = 3 in., temperature = 80°F, 16% Al in propellant)

propellant sample. The side and rear photo diodes detect ignition of the propellant sample. Further refinement of the control system circuitry has just been completed.

After the cognizant engineer and test technician had become familiar with the operation of the facility, a preliminary standard operating procedure for furnace operation and ignition testing was prepared. It has been modified as more operating experience with the furnace has been gained.

As a part of the propellant sterilization program being carried on at JPL, ignitability tests were conducted with three different propellants used in the program. For each propellant tested, ignition samples were machined from untreated bars and from bars of propellant that had undergone 1, 2, and 3 cycles of heat sterilization at 145°C. Each cycle was 36 hr in duration. Ignition delay times were determined for samples tested in a nitrogen flow environment at an approximate radiative flux level of 33 cal/cm^2-sec and a pressure of 24 psia. Table 1 shows the results of these tests. For all three propellants the ignition delay times showed a marked decrease after one heat cycle and a slower decrease with each additional cycle. The ignition delay times for the Rocketdyne propellant did appear to stabilize after three heat cycles.

Figure 6 shows the results of tests performed to determine the ignitability characteristics of a Naval Ordnance Test Station (NOTS) composite solid propellant, A-87. It was determined by JPL as a participant in the Interlaboratory Solid Propellant Ignition Exchange Program. The results were similar to those obtained by

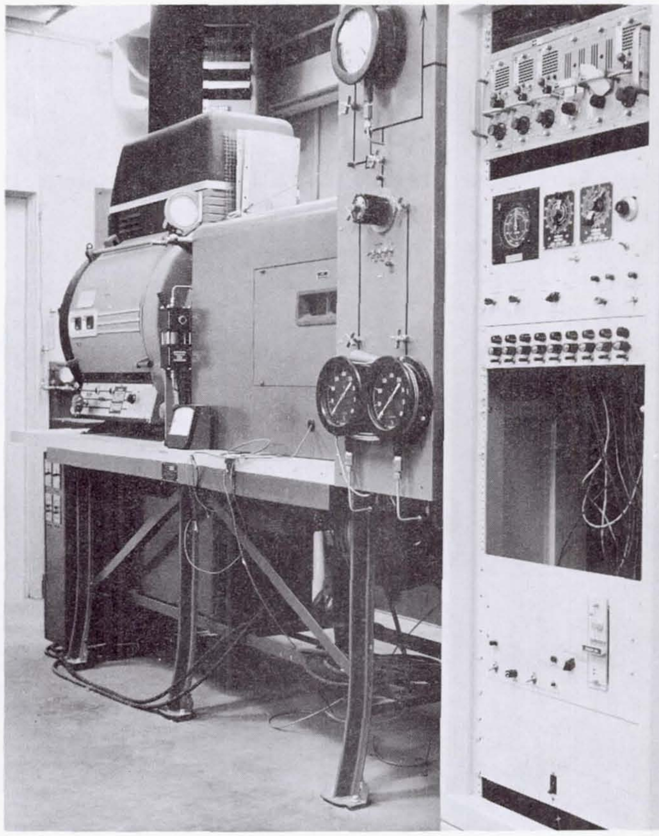


Fig. 4. Arc imaging furnace installation

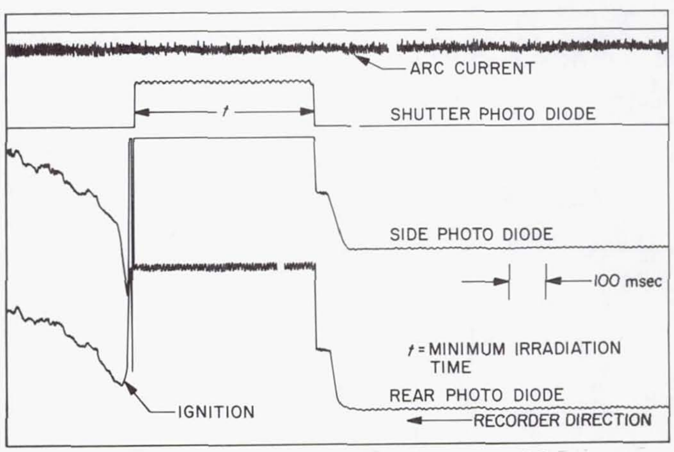


Fig. 5. Oscillograph trace of arc imaging furnace ignition test

Table 1. Ignitability tests of sterilized propellants

Test description

Flux-time characteristics of shutter: total rise time approximately 6 msec
Calorimeter: slope type
Gaseous environment and flow arrangement: nitrogen, low flow rate
Preparation of sample surface: machined
Dimensions of sample: 0.25 in. diameter
0.10 in. thick

Test conditions

Pressure: 24 psia
Initial sample temperature: 80°F

Propellant	145°C conditioning time, hr	Nominal radiative flux density, Cal/cm^2-sec	Ignition Delay*, msec
Aerojet AN583AF	0	33 ±2	630
	36		580
	72		500
	108		440
Thiokol TP-H-3105	0	33 ±3	1590
	36		250
	72		220
	108		145
Rocketdyne RDS-510-2A	0	35 ±3	260
	36		130
	72		94
	108		100

*Maximum error for values ≤ 500 msec to 25 msec.

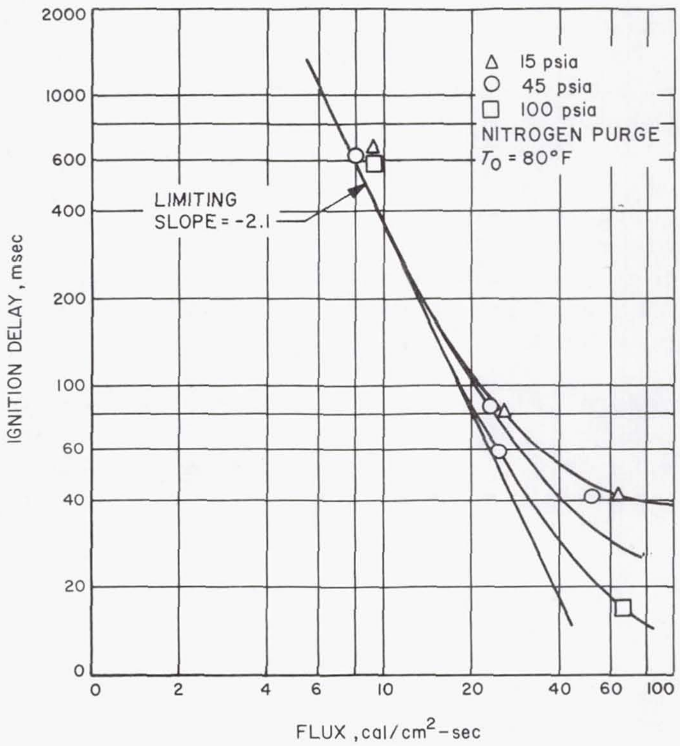


Fig. 6. Ignition delay versus flux for NOTS A-87 composite solid propellant

other investigators; the ignition delay time becoming pressure-sensitive with increasing radiative heat flux.

JPL was represented at the first day's session of the Third Arc-Imaging Furnace Ignition Conference. The conference was held at the Naval Ordnance Test Station on May 24-25. Other representatives were in attendance from NOTS, Stanford Research Institute, Bermite Powder, Aerojet, Hercules Powder, Naval Radiological Defense Lab, Hill Air Force Base, Lockheed Propulsion, United Technology Center, and Hy Cal Engineering. Subjects discussed were radiation calorimetry and test bomb flushing. A panel was formed to draw up a draft of suggested calibration and test techniques for agency standardization in these areas.

SPS 37-33, Vol. IV will contain a report describing the test facility and latest test work in detail.

Planned activities for the next 6-mo period include the incorporation of an oscillograph recorder into the console shown in Fig. 4 and complete ignitability characterization of the heat-sterilized propellants previously tested at the one flux level and chamber pressure.

NOZZLE THRUST MISALIGNMENT

Fabrication of the gas-flow nozzle test assembly has been completed. The symmetrical and asymmetrical nozzles were leak tested at the JPL wind tunnel and

found sound. Minute hair-line cracks along the inside surface of a weld in the plenum chamber were ground out and rewelded. The plenum and supply section valve have been hydro-tested to 1400 psia. The Leg 2 supply pipe and valve, plenum chamber, symmetric nozzle, multiple pressure measuring system (MPMS), and the diffuser pipe and valve that connects into the hypersonic tunnel are in place (Fig. 7). The MPMS has been checked in the system in conjunction with the computer that will be used to acquire and reduce the data. All the transducers to be used in the MPMS have been calibrated. The necessary wiring modifications to incorporate Leg 2 into the hypersonic wind tunnel valve and interlock system have been made and checked out. The checkout revealed several small needed refinements to the system that are now being made.

A computer program is being written that will be used to calculate side forces from the static wall pressure data for the asymmetric nozzle. A theoretical analysis of the two-dimensional flow field within an asymmetric nozzle is underway as a means of attempting to define the problem and the experimental trends analytically.

Within the next 6-mo period the experimental data will be obtained and analyzed, and the theoretical analysis completed.

IMPULSE BOMB

Theoretical analysis has shown that, in a properly designed program of experiments, the specific impulse and other performance parameters of propellants may be determined from the transient pressure measurement when the propellant is burned in the impulse bomb. It has been shown that approximations because of the presence of solid combustion products, and variation of heat capacity and average molecular weight of the gaseous combustion products with temperature and pressure, may be eliminated. Errors introduced by heat transfer to the bomb material are small because of the short burning time, but the analysis includes what is thought to be an adequate method of calculating these as well.

A number of test firings have been conducted to check out the existing apparatus. Calculation of specific impulse from these measurements (on JPL 540 propellant) were in good agreement with the results of motor firings. Firing times are kept in the neighborhood of 10 msec. Longer burning times would unduly increase heat transfer losses while shorter burning times would begin to strain the response time capability of the pressure transducer and its supporting circuitry. Unfortunately, this has made the actual measurement of the pressure transient rather difficult. Present measurements are made from photographs of oscilloscope traces. It was felt that more sophisticated instrumentation was necessary before quantitative results were possible. As a result, experimental work has been temporarily suspended.

Documentation detailing the thermodynamic and heat transfer analyses is now in preparation. A small computer program to do the complex calculations of the more exact analysis is in the planning stage.

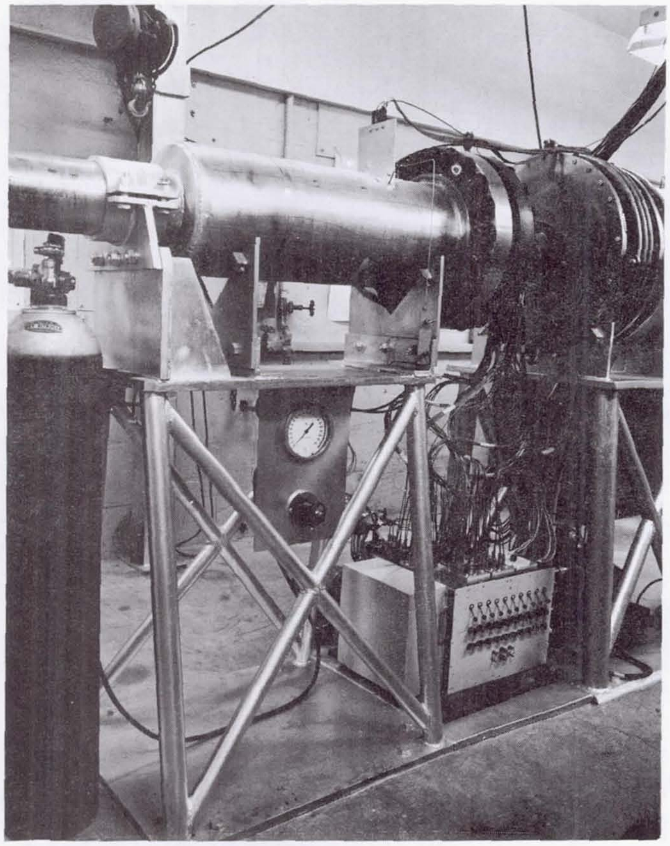


Fig. 7a. Test assembly
(Front view)

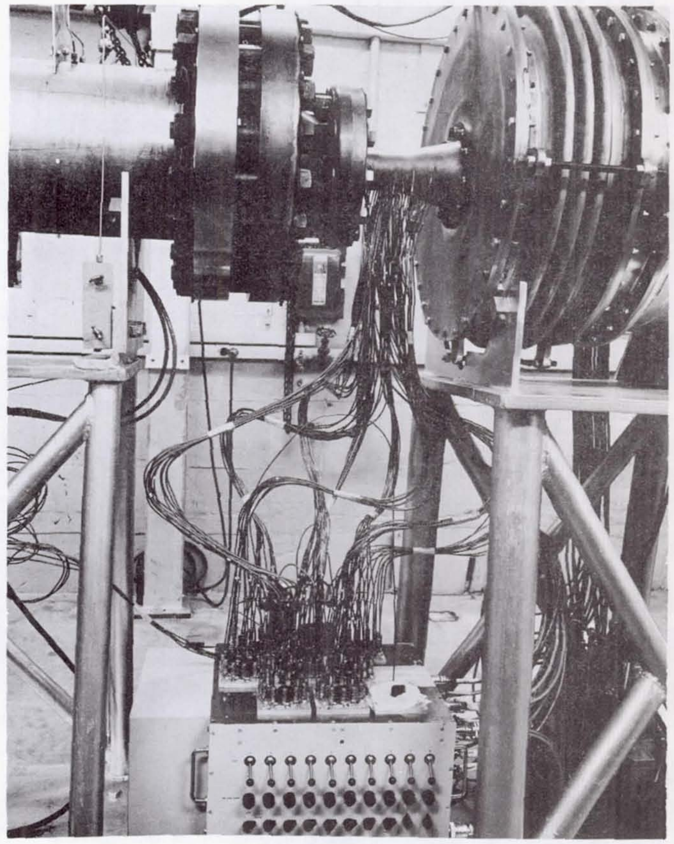


Fig. 7b. Test assembly
(Side view)

NOZZLE HEAT TRANSFER

Work in this area has consisted mainly of theoretical developments and computer programs that permit more accurate calculation of heat transfer in rocket nozzles of practical design. Work in the theory of conduction heat transfer has consisted mainly of the development of a more unified theory, independent of the coordinate system. This, then, permits the tailoring of the coordinate system to the nozzle under consideration, thus simplifying the application of the boundary conditions and making more accurate calculations possible. Other effects considered are time-dependent convection boundary conditions and the variation of thermal properties with position, temperature, and direction. Sturm-Lioville theory has been generalized to include these effects. In this connection, several important and general theorems have been proven. Where the complexity of the problem precludes even the use of this theory, the method of Galerkin is explored to some depth. This work will be documented in a technical report.

A second area of endeavor has been that of the calculation of heat transfer in heavy-hardware (i. e. test) motors. This work was motivated by discrepancies between measurements of performance in heavy-hardware and flight-weight motors, sometimes attributed to the difference in heat transfer. Theoretical work consists of a computer program to simulate the firing of small test motors. The mathematical model includes the effects of variation of pressure and temperature with

time and location, and calculates heat transfer as well. This program is now under development. As a first attempt to verify these calculations experimentally, a number of motor firings have been planned. The motors will be fired vertically in an oil bath then, at the end of the firing, submerged completely. Depending on the temperature rise of the oil, the total heat transfer may be calculated for comparison with that predicted by the computer program.

A third area of endeavor has been the development of a computer program to calculate heat transfer in composite nozzles of complex geometry. It is more specifically geared to nozzle problems than the now used "general" heat conduction programs. It includes the effect of the unsteady-state, variable thermal properties and, unlike present programs, shifts the burden of the complicated geometrical calculations to the computer as well. The concept of the calculation is not new, but provision is made in the inputs for "guiding" the calculation based on "engineering intuition." It is thought that this will help minimize stability and round-off error problems, and increase the speed of the calculation. The program is written with ease of set-up and application, and inclusion of time-varying convection boundary conditions in mind. This program is also now under development, but preliminary calculations have been very encouraging. It is thought that, when completed, it will have immediate application to nozzles of current design interest.

LIQUID PROPELLANT EXPERIMENTAL ENGINES AND SOLID PROPELLANT EXPERIMENTAL MOTORS (731)

Page Intentionally Left Blank

ADVANCED LIQUID PROPULSION SYSTEM (ALPS)
NASA Work Unit 731-00-00-01
JPL 328-10101-2-3840

ALPS SYSTEM DEVELOPMENT

Computer programs were used to calculate the system flows, pressures, and temperatures that would be expected within a 2000-lb thrust ALPS system operating at full thrust for 700 sec under 1, 0.5, and 0.1 g with initial propellant bulk temperatures of 40, 70, and 100°F. This parametric design analysis will be extended to cover throttling to 50 and 10% of rated thrust (for the same g and bulk temperatures). Also, fixed thrust systems rated at 6.7°K and 200 lb thrust will be analyzed for the same conditions to check the effect of scaling. If personnel are available, a new digital program to analyze transients will be written and used during FY 1966; the contract engineer who performed the above work was terminated as part of the general release of contract employees at JPL at the end of FY 1965.

Three tests of an ALPS pressurization circuit mockup were made during the last quarter of FY 1965. In these tests, the ALPS components that comprise the circuit were used to pump water from a heavyweight test tank. The first two tests were unsuccessful because of component malfunctions; a pressure surge on start, originating in the gas generator, damaged a heat exchanger and several hot gas leaks occurred during the first test; the second test was terminated when the general controller failed to regulate properly so that excessive flows were permitted (this damaged a second heat exchanger). Two separate firings were made during the third test to demonstrate shutoff and restart characteristics as well as regulation characteristics during both steady and transient flow conditions. This last test was highly successful and a great amount of data was gathered; the only malfunction was a slight hot gas leak through a weld on the gas generator during the last few seconds of the test. Additional tests are planned for early FY 1966. The contract engineer who conducted the above tests also was terminated at the end of FY 1965.

ALPS EXPULSION DEVICES DEVELOPMENT

A number of potential bladder materials, including nitroso rubber, were subjected to permeation testing during FY 1965. Nitroso rubber terpolymer (made by Reaction Motors Division of Thiokol) is the first elastomer JPL has found to be even fairly compatible with N_2O_4; it is highly permeable, however, Teflon redundant film (made by Dilectrix Company) has demonstrated remarkable durability (10 to 100 times better than TFE-FEP Teflon laminate) on the JPL crease tester. After a long delay, a contract amounting to $44,000 has been signed with Dilectrix to make samples of several candidate composite materials of redundant film, metal foil, and Teflon felt for evaluation followed by fabrication of 18-in. hemispherical bladders of the selected material. These bladders should be delivered around January 1966. Plans are also being made to secure another contract (amounting to approximately $100,000) to fabricate bladders to JPL design (as generated) so that the results of tests can be exploited as soon as available; the present contract with Dilectrix specifies, in advance, most of the design features. Also, during the first quarter of FY 1966, it is planned to secure a contract for about $50,000 to have an impermeable elastomer for N_2O_4 synthesized. A report summarizing the work on bladders at JPL is almost finished.

The Aeronautical Division of Honeywell is continuing the development of convoluted diaphragms under a $42,000 contract. Attempts to improve the recycleability of aluminum (type 1100) diaphragms by forcing even movement of the convolutions failed because of buckling in the outermost reflected surface. Up to three cycles have been achieved by reinforcing the forward surfaces but this result is not reproducible; so, future efforts will be concentrated on prevention of the buckling. Also, attempts are to be made to produce diaphragms of stainless steel and titanium. This contract will probably be completed by the end of the second quarter FY 1966. A report summarizing the work with convoluted diaphragms is being written.

Arde Inc., Paramus, N. J., has a $20,000 contract to develop 18-in. hemispheres of stainless steel with folding control rings attached. This company has demonstrated that such a device will reverse itself into a mirror image configuration and return several times. A 4-mo delay was encountered in securing a small supplement to the contract so that replacements could be obtained for the defective hemispheres originally supplied to them by JPL. The current plans call for Arde to make four expulsion diaphragms, two of which are to be delivered to JPL (around October 1, 1965).

Internal JPL chemistry support of the bladder development has diminished during the last quarter of FY 1965. Transfer of personnel to other programs has ended work on the lead-plating and permeation tester development. On-lab testing of bladders and performance of crease tests will be seriously curtailed in FY 1966 because of release of the Laboratory's contract technicians.

MATERIALS COMPATIBILITY TESTING

A facility to test approximately 1000 materials samples, each in N_2O_4 and N_2H_4 for extended periods at controlled temperatures (up to 150°F) is scheduled to become operational during the third quarter of FY 1966 at JPL's Edwards Test Station. The racks for holding the samples are completed, the instrumentation system is to be delivered early in FY 1966, and the building has been approved by NASA and is being designed. The glass capsules are on order. The procedural specifications are nearly complete and will be finished as soon as the details of the technique for bonding the strain gages on the capsules is finalized. A report describing the procedures and equipment design is scheduled to be published around January 1966.

A large flight-weight fuel tank of 2014-T4 aluminum was sectioned and metallurgically analyzed after hydrazine had been stored in it for almost 4 yr. The tank was in good condition. The hydrazine was analyzed, checked for physical properties and ignition lag (with N_2O_4), and then used in firing tests to see if the combustion was as smooth as with control hydrazine. Results are being analyzed. This entire test program is being documented in a formal report that should be published during the second quarter of FY 1966.

ADVANCED LIQUID PROPULSION SYSTEM COMBUSTION DEVICES
NASA WORK UNIT 731-00-00-02
JPL 328-10301-2-3840

The primary goal of this work unit is the development of a liquid rocket engine and a gas generator for the ALPS. The secondary goal is the advancement of the state of the art of liquid rocket injectors and thrust chambers. This task is subdivided into three development areas: injector, thrust chamber, and gas generator. Progress in all these areas was not as rapid as anticipated because of the prolonged procurement freeze, resulting from a delay in availability of 328- job number funds. Unfortunately, each area had major procurement actions delayed several weeks by this situation.

INJECTOR STUDIES

A major activity of the ALPS Injector Program has been the investigation of reaction effects on the combustion process. The extremely rapid reaction rate of the hydrazine-nitrogen tetroxide propellants can result in the disruption of the mixing process, resulting in low efficiencies with some impinging-doublet injector designs. During this period, additional stream separation experiments were completed at the 100-lb thrust per element scale. These results were described in JPL SPS No. 37-31, Volume IV. The results from these tests were similar to those of the 2000-lb scale, although less severe reaction effects were noted. This work is being extended to the 10-lb thrust per element scale. Some work was completed at this scale during the past 6 mo, and it is anticipated that this program will be completed and the results available by the end of the first quarter of FY 1966. A companion study of the basic N_2O_4-N_2H_4 reaction has been completed by Dynamic Science Corp. under contract to JPL. The purpose of this study was to gain an understanding of the basic reaction mechanism, with the hope that chemical additives could be added to inhibit the reaction and thus avoid the reaction effects noted above. The results of this study were published in JPL SPS 37-33, Volume IV. Briefly, it was found that the N_2O_4 and N_2H_4 propellants were almost completely immiscible, and that the reactions involved are extremely rapid, so that the surface reaction could well evolve sufficient heat and gas to seriously affect the mixing process. Although this study has been completed, it is planned to continue the basic approach because some of the results are believed to be applicable to the ignition spike problem. This will be carried out through another contract that will be let during the second quarter of FY 1966. A technical report describing the 2000-lb thrust stream separation studies will be published during July 1965.

As a result of the problems encountered above, the ALPS injector effort has been redirected toward multielement impinging-sheet injectors. During this report period, the design and fabrication of a 10-element impinging-sheet injector at the 100-lb thrust level was completed. This injector was designed to operate with film-cooling only and is constructed of molybdenum, a highly conductive refractory metal. An integral valve was also designed and fabricated. This valve features direct, smoothly-transitioned flow into each injector orifice, with sealing directly upstream of the orifices to obtain minimum manifold volume. It is anticipated that these factors will produce smooth operation with a minimum of pressure transients at ignition and shutdown. Assembly of this valve will be completed, and test firings

will be conducted with the injector-valve combination during the next 6-mo period. In addition, the design has been completed for a heavyweight, 2000-lb thrust, 80-element impinging-sheet injector using the design criteria developed at the 25-lb element level. Fabrication and assembly of this injector will be completed during the second quarter of FY 1966.

THRUST CHAMBER DEVELOPMENT

The ALPS thrust chamber task has concentrated primarily on pyrolytic graphite alloys for chamber construction. During this period, a water-cooled 2000-lb thrust injector that will be used to conduct long-duration firings with free standing pyrolytic graphite thrust chambers was fabricated. Unfortunately, problems were encountered with the water-cooling passages, and this firing program was delayed. Suitable repairs have now been completed, and it is anticipated that long-duration firings will be conducted during the next period. As reported in SPS 37-33, Volume IV, evaluation firings were conducted on several ablative thrust chamber designs at the 100-lb thrust level. The purpose of these firings was to evaluate the design and fabrication ability of several contractors and to determine the capabilities of typical ablative thrust chambers with hard throat inserts. These chambers were subjected to a severe environment with N_2O_4-N_2H_4 propellants at 150 psia chamber pressure, a 1.20 mixture ratio, and a characteristic velocity, c*, of 5500 ft/sec. Two designs, those of Avco and Thompson Ramo Wooldridge (TRW), exceeded 500-sec duration firings. Shutdown was carried out when chamber pressure reached 120 psia. Both these designs featured silicon carbide throat inserts.

A contract was let to Solar Aircraft to continue a pyrolytic graphite braze development program, started during the first half of FY 1965. This contract, scheduled to be completed by the end of December 1965, calls for the brazing of cylindrical samples, followed by the brazing of metal injectors to pyrolytic graphite thrust chambers. Although previous results have been encouraging, this is a particularly difficult task because of the large differential in coefficients of expansion. The design of a thrust chamber and associated apparatus to provide the ability to withdraw gas samples from the boundary during a firing has been completed. Fabrication of parts will be completed during the first quarter of FY 1966, and it is now planned to award a contract for the actual testing and analysis of gas samples. This 100-lb thrust work supplements the previous work with this injector type so that the full characterization of this injector will be obtained. This characterization now includes heat flux, mass distribution, and mixture ratio distribution data. The thermal analysis has been completed for a so-called composite thrust chamber, which is designed to withstand 1000 sec of operation with an outside wall temperature not exceeding 400°F. This composite chamber study consists of an inner pyrolytic graphite liner, a layer of pyrolytic graphite insulating tape, and an outer insulative layer of quartz fiber material. The primary problem area is that of attaching the injector to the chamber. It is hoped that the braze-development work being pursued by Solar Aircraft will aid in the solution of this problem. One possible approach to this problem is the use of a high-temperature gasket between the thrust chamber and injector assembly. In this respect a gasket tester has been designed, and gaskets of several different compositions will be tested to determine the feasibility of this approach.

The thrust chamber development program has been following the progress of Contract NAS 7-113 with IIT Research Institute. Because the materials being developed under this contract lend themselves to more conventional attachment techniques, including welding, it may prove desirable to use these types of materials in the composite design, rather than the pyrolytic material. If this becomes apparent, plans will include the purchasing of some of these materials to incorporate in the composite approach.

Although it has been possible to conduct firing durations of about 5 min with free standing pyrolytic graphite chambers with a high performing injector of the Mod-IV configuration, a design has been completed for a film-cooling adapter to be used in conjunction with this injector. Firings will be conducted with film cooling to demonstrate the ability of this material to operate for long durations with a moderate amount of film cooling (10% or less).

GAS GENERATOR DEVELOPMENT

During this period, the gas generator development program included the fabrication and firing of a throttlable version of the previously described radial-spraying multiorifice injector with the Shell Development Co. spontaneous catalyst. Although limited throttling was carried out, a problem was encountered at shutdown with propellant decomposition within the injector head. One fix was attempted to solve this problem, and it is believed to have been successful, although a test technician error invalidated the test. Because of decreased manpower availability and the termination of the services of a contract engineer performing this task, the decision was made not to continue further gas generator development during the next fiscal year.

Page Intentionally Left Blank

ADVANCED LIQUID PROPULSION COMPONENTS
NASA Work Unit 731-00-00-03
JPL 328-10201-2-3841

The objective of this work unit is the development of specific components needed in a future space exploration vehicle using the ALPS concept. Each component design formulated is intended to be an advancement in the state of the art. This new generation of devices will satisfy the requirements for valves (and their control mechanisms) that are extremely reliable and have accurately repeatable performance while operating during the mission and in the space environment for periods up to 2 yr.

A considerable amount of work has been done on two components. These are the generant tank and cell assembly, and generant controller.

GENERANT TANK AND CELL

Three flight type titanium generant tanks were subjected to acceptance test programs at the component level over the operating range of 0 to 1500 psig. One unit completed all testing satisfactorily and was delivered for further testing at the system level. The other two units experienced failures in the elastomeric diaphragm that were the direct result of handling and method of test. One of these units was repaired and the repaired unit was retested; all results were satisfactory. In addition, expulsion tests using distilled water were performed at temperatures ranging from 40 to 100°F. The pretest temperature conditioning periods varied from a minimum of 24 to a maximum of 72 hr. During these environmental tests, expulsion appeared to be normal and any increase in pressure that might be anticipated from deforming the diaphragm at 40°F was not noticeable in the low temperature expulsion test results. The third unit is in the process of being repaired; this tank assembly is scheduled for long-term hydrazine storage test at the Edwards Test Station.

GENERANT CONTROLLER

The current design of the generant controller is shown in Fig. 1. This configuration has been subjected to a considerable amount of testing. The assembly operates stably and with a reasonable amount of precision resulting in acceptable performance except for somewhat high hysteresis in one operational mode. The design does not reflect the best hysteresis characteristic during instantaneous reversals of stroke, such as would occur during engine throttling. With the specimen installed in a test circuit simulating the normal operation (i.e., remotely sensing an ullage/liquid volume), the approximate hysteresis value is 10 lb/in.^{2} above the regulation pressure. Means to reduce this value to a more acceptable level are being investigated.

After completing the above performance tests, two units were delivered for ALPS testing. For purposes of this system phase, each controller was preset at different pressure levels with the maximum set point of 255 psig and a minimum of 215 psig. In addition, another unit is being assembled for further testing at the component level.

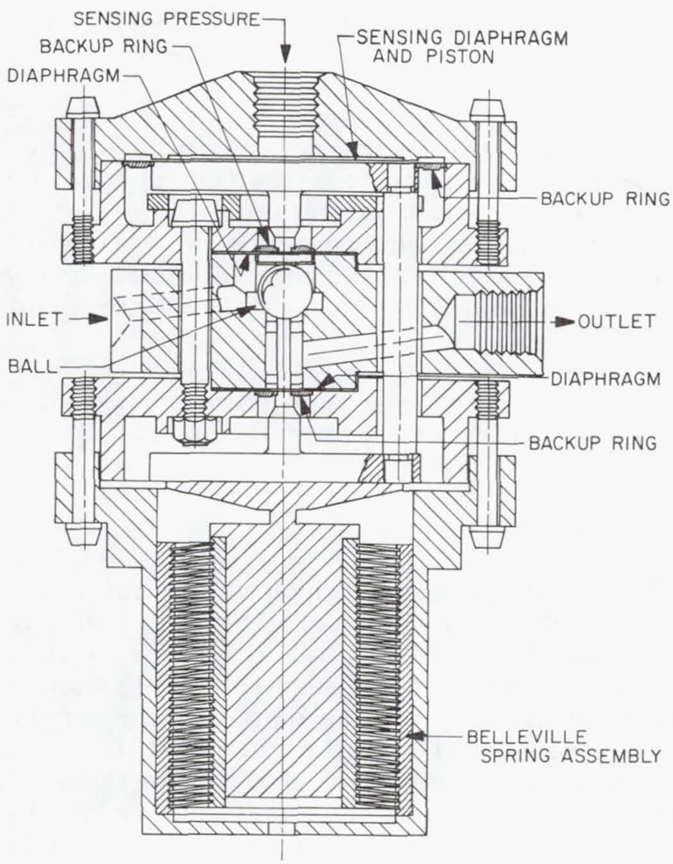


Fig. 1. Cross section of ALPS generant controller

Reports covering both the generant tank and cell, and generant controller have been included in SPS 37-32 and 37-33, Vol. IV.

RESEARCH PROGRAM (129)

Page Intentionally Left Blank

FLUID PHYSICS RESEARCH (129-01)

MOLECULAR SPECTROSCOPY
NASA Work Unit 129-01-01-01
JPL 329-10101-1-3260

The microwave spectroscopic analysis of 2, 4-dicarbaheptaborane (7) has been completed and submitted for publication in the Journal of Chemical Physics. Six isotopic species of this molecule were analyzed. It was shown that the molecular skeleton exists in the form of a closed cage with a five membered base ring containing two nonadjacent carbon atoms. The electron distribution between the carbon and boron atoms in this molecule is unusual. It appears that the carbon and boron atoms are electron deficient and participate in three center bonding. The corresponding experimental work on 2, 3-dicarbahexaborane(6) has been brought to a stage of near completion and a preliminary report of the results has been summarized (in SPS 37-33, Vol. IV), and presented at the Molecular Spectroscopy Symposium at the Ohio State University on June 16, 1965. Six isotopic boron species of this molecule have been analyzed. Two carbon-13 isotopic species remain to be done to complete the study.

A feasibility study concerning the microwave spectra of unstable molecular species has been completed. It was concluded that an investigation of such unstable species is practical and that the potential results of this research would be extremely useful in the study of both planetary and interstellar atmospheres. Because of the experimental problems that are expected in such studies, preliminary experimental work would be restricted to the more prominent species (OH, CH, and NH) that are present in the planetary atmospheres of Mars and Jupiter. The present plans are to examine the OH radical to permit elucidation of the experimental techniques, and then to study CH and NH radicals.

A microwave absorption cell has been designed for the study of unstable molecular species. The main vacuum chamber has been constructed, but has not been vacuum tested. Preliminary performance tests are being conducted on the microwave properties of the microwave absorption cell that is to be installed in the vacuum chamber. A set of microwave wave guide transitions, which are required to adapt the microwave absorption cell to the main microwave equipment, are being designed and fabricated. The microwave system must have a low residual Voltage Standing Wave Ration throughout the working microwave frequency bands between 8, 000 and 40, 000 Mc.

LOW-ENERGY ELECTRON IMPACT SPECTROSCOPY

The fabrication of the vacuum chamber, electron energy selector and analyzer, electron gun, electron focusing lens elements, and part of the scattering chamber has been completed. The design of the detector system and the focusing elements associated with the scattering chamber has been finished.

The next items on the schedule to design and build the low-energy electron impact spectrometer are:

1. Fabricate focusing elements associated with the scattering chamber.

2. Design and build mounting for scattering chamber, electron gun, energy selectors, and detector.

3. Design and fabricate sample handling system.

4. Design and fabricate Helmhotz coils.

5. Assemble and test components.

The following papers were published.

1. Inducted Infrared Absorption of Solutions of H_2 and D_2 in Liquid Neon, by George E. Ewing and Sandor Trajmar, J. Chem. Phys., June 1965 (Presented at the Symposium on Molecular Structure and Spectroscopy, Columbus, Ohio, June 1965).

2. The Near Ultraviolet Bands of Mg0: Analysis of the $D^1\Delta$ - $A^1\pi$ and $C^{1-}\Sigma$ - $A^1\pi$ Systems, by Sandor Trajmar and George E. Ewing, Astrophys. J., July 1965.

PLASMA SOURCES, GENERATORS, AND ACCELERATORS

NASA Work Unit 129-01-04-01
JPL 329-11101-1-3832

MAGNETO-PLASMA DYNAMIC (MPD) SOURCE

A water cooled MPD plasma source, first described by Ducati, Gianinni, and Muehlberger (AIAA Journal, 1964), has been designed and tested in the latter half of FY 1965. The source has been operated over a current range of 100 to 4000 amp, covering a total input power range of 2.5 to 100 kw with argon mass flows of 0.05 to 1.5 gm/sec.

Extensive diagnostics of the source exhaust have been completed and are reported in Ref. 1. The most important results of the study are:

1. Gas enthalpy calculated from power input, cooling water losses, and gas flow measurements show that at the exit of the source the degree of ionization must be lower than equilibrium based on the spectroscopically determined electron temperature.

2. Immediately downstream of the source exit, impact probe measurements revealed the existance of a barrel shock closed by a normal shock. Downstream of this shock, impact and velocity probe measurements indicate that the Mach number of the plume is close to unity.

3. Measured electron density levels in the plume downstream of the shock region are orders of magnitude larger than electron densities calculated from the Saha equation using measured electron temperatures.

A thrust stand for use in a vacuum tank, at the MPD thrust level, has been designed and fabricated in the last quarter of FY 1965. In the first quarter of FY 1966, thrust measurements will be made with this thrust stand, coincident with the plume diagnostics. In particular, a correlation will be made between measured thrust and measured velocity in the plume to determine the magnitude of jet entrainment.

In the last half of FY 1965, tests were begun with an open MPD source using porous electrodes. Preliminary results indicate that a well collimated beam of plasma is formed, and containment is mainly achieved by the arc's self-induced magnetic field. Large erosion rates of the porous carbon cathodes have been observed at high current levels. Several types of porous and slotted tungsten cathodes are now being fabricated and will be tested in the first quarter of FY 1966 to attempt to limit the erosion rates to acceptable levels. In addition, velocity measurements in the plume will be made with and without material confinement to determine whether the flow can be accelerated at constant pressure to prevent shock formation downstream of the source exit.

ACCELERATOR-GENERATOR STUDY

A computer program to generate both nonequilibrium accelerator and generator flows will be completed in the first quarter of FY 1966. The program includes nonscalar electrical conductivity, nonequilibrium radiation, ionization and recombination rates, thermal conduction, charge exchange, and thermal-electric effects. Preliminary results obtained with a part of the program are reported in Ref. 2 and 3.

Results obtained from the computer program indicate that both MHD power generation and cross-field acceleration are possible using inert gases without seeding at low inlet temperatures (2000 to 3000°K corresponding to stagnation conditions in a nuclear reactor). To determine the feasibility of this concept, both generator and accelerator tests will be conducted with segmented constant pressure test sections.

Initially, steady-state tests will be conducted in a plasma vacuum facility. The test section design will be started in FY 1966 and fabrication should be completed in the second quarter of FY 1966. On completion of the test section and assembly of the necessary diagnostics, experiments will be initiated to determine the degree of electron temperature elevation and the resulting nonequilibrium radiation and ionization. The experimental results will be compared with the computer program described above.

PRESENTATIONS

The paper titled, Nonequilibrium Flows in Crossed Electric and Magnetic Fields, by G. R. Russell, was presented before the NASA Research Advisory Committee on Fluid Mechanics at JPL on May 6, 1965.

REFERENCES

1. Kelly, A. J., Nerheim, H. M., Gardner, J. A., Electron Density and Temperature Measurements in the Exhaust of a MPD Source, AIAA Second Annual Meeting and Technical Demonstration, San Francisco, California, July 26-29, 1965.

2. Russell, G. R., Nonequilibrium Flow in a Linear MHD Generator Utilizing an Inert Gas Without Seeding, International Symposium on MHD Power Generation, Paris, July 1964.

3. Russell, G. R., "The Effect of Electron Drift Velocities and Temperature Gradients in Nonequilibrium MHD Generators," Submitted to Physics of Fluids. June 1965.

MAGNETO-FLUID DYNAMICS
NASA Work Unit 129-01-05-02
JPL 329-10801-1-3270

LIQUID SODIUM TUNNEL

An attempt is being made to observe the details of the flow field created by a body placed in a stream of electrically conducting fluid flowing along a magnetic field.

Measurements of the drag experienced by a sphere and a disk, both with 1/2 in. diameter, have indicated several regions of possible interest. When N (ratio of Lorentz to inertia forces) is large, there is virtually no difference between the drag of these two objects, the drag of which differs by a factor of two with no applied field. This suggests that the flow field for the two objects is identical and is probably approaching the slug-like condition described in previous reports. Such a conclusion is verified by the detailed measurements of the wake downstream of the body. This wake varies from its conventional shape when $N = 0$ to a fully stagnant form as N becomes large. As yet, nothing is known of the nature of the forward wake. It is difficult to introduce instrumentation into this region without seriously disturbing the flow we wish to observe. A sphere around which one can measure the angular distribution of pressure has been made and will be used to observe the consequences of applying a magnetic field and further to find the consequences of introducing upstream instrumentation into the flow. It is believed that such pressure measurements will be interpretable in terms of a slug-like flow field and finally verify the existence of such a flow field.

To more fully observe the steps in the formation of the downstream slug flow as N is increased, the flow about a slender body has been investigated. Here we are looking at a flow that is not already separated, as are the sphere and disk wakes, and can observe the very profound effect the magnetic field has on the wake width and velocity defect. The application of a very small field causes a considerable widening of the wake, which is believed to be caused by a profound change in the boundary layer on the body; it either becomes considerably thicker or actually separates from the body. As N is increased, these wakes also tend to a slug flow essentially indistinguishable from sphere or disk wakes.

The apparatus has been considerably improved by connecting the magnet to a very low ripple, easily controllable unipolar generator. A new traversing mechanism has been designed and built, and we can now run electrical and pressure measurements in rapid succession and reduce the down-time of the equipment.

MOTIONS OF A ROTATING FLUID

The Taylor Problem

As a body moves along the axis of a rotating fluid, it produces a flow field that has several features in common with the previously discussed magneto-fluid dynamic case. Slug flows are produced when the ratio of Coriolis to inertia forces

(S) is large. In contrast to the theoretical predictions in such a case, the wakes formed upstream and downstream of the body are not symmetrical in the axial coordinate. The forward slug eventually reaches a length that is only a function of (T), the Taylor number [ratio of Coriolis to viscous forces], while the rearward slug is much larger, often at least as long as the fluid container. Associated with these flows is a drag coefficient that is a linear function of S when S is larger than 10. When S is small, less than 0(1), the drag is less than the drag with no rotation. Between, the drag is not a simple function of any single parameter but a complicated function of S and T separately.

Studies of Rotating Boundary Layers

Preliminary studies of the complex flow created by the strong interaction of the boundary layer on a stationary disk and rotating outer flow, indicated the need for a more versatile and controllable apparatus. This has been designed and built.

Initial results have substantiated the belief that both the boundary layer and its outer flow are strongly affected by the nature of the boundary conditions imposed at the edge of the disk. Further investigations of this and many allied problems are to be continued for some considerable time.

SHOCK-HEATED PLASMAS AND JET STRUCTURE
NASA Work Unit 129-01-05-03
JPL 329-11301-2-3270

JET STRUCTURE

Preliminary attempts have been made to measure the rotational temperature distribution in the free jet. The spectrometric technique described by Muntz[1] has been used. This method involves exciting the nitrogen gas flow by means of an electron beam and determining the rotational temperature of the gas from an examination of the rotational fine-structure of the resulting radiation. The electron beam used for the detached shock structure study described above is used to excite the nitrogen flow; initial examination of the radiation revealed some signal-to-noise problems that appear to be solvable. A pulse unit for switching the electron beam at 1 kc has been built; this will allow phase-lock techniques to be applied to the output of the spectrometer and affect signal-to-noise increase. A 750 mm f/6.3 spectrometer has been ordered.

USE OF HIGH ENERGY ELECTRON BEAMS IN NEUTRAL AND PARTIALLY IONIZED GAS FLOWS

Multiple Scattering Experiments

Previous electron beam absorption and fluorescence experiments to measure gas density have been limited to low density flows to avoid the problem of multiple scattering. An understanding of the multiple scattering process is necessary for the proposed experiments in partially ionized gases.

Experimental equipment has been constructed to make detailed position-distribution measurements of electrons scattered by gas atoms under steady conditions. This equipment is shown in Fig. 1 and consists essentially of an electron source to provide a collimated beam of electrons and a Faraday cage detector that can be accurately located with respect to the beam axis. An intermediate pumping chamber has been added to the system to reduce pressure fluctuations in the gun environment because of pressure variation in the scattering section. This has helped to stabilize the electron beam current, but there is still some problem caused by beam deflection because of variable gun conditions. A new electron gun designed to provide highly collimated beams at acceleration voltages of 5 through 15 kv has been tested. It was found to be too inefficient to provide sufficient current for fast measurements.

Initial measurements have been made in the single scattering regime, which is well understood, to check out the equipment and technique. By varying the gas density it is possible to change from the single to multiple scattering regimes, and this will be done after a modification of the equipment to control the beam deflection.

---

[1] Muntz, E. P., "Static Temperature Measurements in a Flowing Gas," Phys. Fluids, Vol. 5, No. 1, pp. 80-90, Jan. 1962.

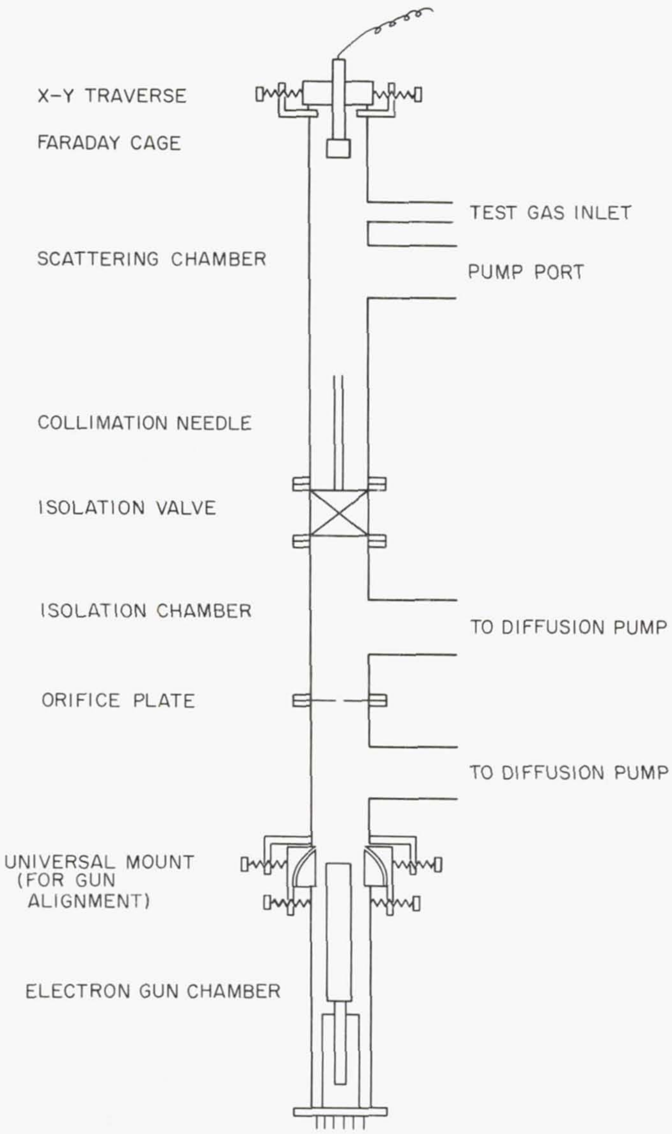


Fig. 1. Gas density measuring equipment

Analysis of Partially Ionized Flows

This experiment awaits the availability of the free-piston shock tube to generate a partially ionized gas behind the incident and/or reflected shock wave. It is planned to use the electro gun equipment already constructed for the multiple scattering experiments.

SHOCK-WAVE STRUCTURE

The proposed experiment seeks to obtain velocity distribution function information through the resonant scattering of an intense light source off excited atoms. As a first step, a study has been undertaken of resonant scattering from gas atoms that have been excited by an electron beam. Phase-lock detection techniques

are used in conjunction with low-noise photomultipliers. A low voltage (100 v) electron beam has been constructed, and attention has been directed to the 2^3S metastable state of helium. Resonant scattering or absorption of an external capillary discharge tube have not been detected on the 3889 Å line, but there is reason to expect that it will be seen on the 10,829 Å line. This will be checked in the near future. It is hoped that more experimental sensitivity to resonant scattering of other wavelengths can be achieved through the development of more intense electron beams and discharge-tube sources.

Page Intentionally Left Blank

PLASMA TRANSPORT PROPERTIES, SHOCK WAVES
AND INELASTIC RATE PROCESSES
NASA Work Unit 129-01-05-04
JPL 329-11201-1-3832

ELECTRON RECOMBINATION RATES

The discharge tube and associated equipment for the recombination rate experiment have been assembled and preliminary experiments have begun. A pyrex tube 60 cm long and 50 cm in diameter will be filled with gases (argon is now being used) at pressures from 1μ to 100μ. A capacitor bank (3000 J) is triggered to discharge through the tube. After the cessation of the discharge, the time rates of the decay of electron temperature and density are observed. The dimension of the discharge tube is so chosen to assure that the diffusion of the charged particles in the whole range of electron density (10^9 to $10^{15} cm^{-3}$) and electron temperature (300 to 16,000°K) produced in the discharge is negligible in comparison with that because of recombination. The electron density as a function of time is measured by observing the continuum radiation at 5530 Å and ion probe output. Both of these measurements are calibrated by using a microwave cutoff point. The electron temperature is measured by using the spectral line ratio method and the triple probe method. The high quantum number argon lines 4259 and 4158 Å are chosen in the temperature measurement to assure that their populations have Boltzmann distributions. The results of the electron density measurements obtained from continuum intensity and ion probe measurements agree within 30% throughout the duration of the decay when both data are normalized to the microwave cutoff point[1]. The electron temperature measurement by spectroscopic and probe methods cannot be made much below 4000°K for the conditions of the experiment. The electron temperature below 4000°K is obtained from an extrapolation by using the electron energy equation. The atom temperature has to be known to make such an extrapolation. Because of the high electron temperatures and densities attained in the initial discharge, an appreciable amount of energy is transferred to the atomic component of the plasma during and before the period when the recombination rates are measured. Because of the increase in the atom temperature, extrapolation of the electron temperature cannot be made assuming a final value for the atomic temperature. Therefore, work is being carried out to measure the plasma pressure so that the temporal behavior of the atom temperature can be determined. A strain gage pressure transducer has been used for this measurement. Because of its slow rise time, only the asymptotic portion of the pressure response is used to evaluate the atom temperature. Pressure gages with a rise time of better than 100μ sec at a pressure of the order of 1 mm Hg are required. A gage is being designed to satisfy the requirements mentioned above and testing will begin at the start of FY 1966. On completion of the pressure gage tests, electron recombination rates will be measured in the inert gases and inert gas mixtures. At low electron temperatures, where dissociative recombination is a possible recombination mechanism, a mass spectrometer will be used to measure the molecular ion production rate because this production rate may limit the dissociative recombination rate. Experiments using the mass spectrometer will not be started until the end of the first half of FY 1966.

[1] Chen, C. J., "Anomalous Diffusion and Instabilities of Argon Plasma in a Strong Magnetic Field," submitted to Phys. Fluids, also JPL 32-695.

Three body-radiative recombination rates have been measured in argon over an electron temperature range of $1000 < T_e < 16,000°K$ and an electron density range of $10^9 < n_e < 10^{15}$ cm^{-3}. The data is in general agreement with the theoretical work of D. R. Bates, A. E. Kingston, and R. W. P. McWhirter (Proc. Roy. Soc., Vol. 267 and 270) and S. Bryon, R. C. Stabler, and P. I. Bortz (Phys. Rev. Let., Vol. 8, No. 8).

SHOCK WAVE STRUCTURE

In the first quarter of FY 1966, after completion of a feasibility study of using Thomson scattering of a laser beam to measure electron densities, an experiment will be undertaken to measure electron temperature and density gradients in and adjacent to a shock wave in a partially ionized gas. A standing shock wave will be produced in the exhaust of four MPD arcs in a vacuum plasma facility. It is expected that the shock wave thickness, based on atom-atom collisions ahead of the shock, will be of the order of several centimeters. The electron density gradients in and adjacent to the shock will be measured by Thomson scattering from a giant-pulsed laser. Electron temperatures will be measured using relative-line intensity techniques. The experimental work will be compared to the theory of M. Y. Jaffrin (Phys. Fluids, Vol. 8, No. 4).

PRESENTATIONS

The paper titled, Anomalous Diffusion and Electron Recombination, by C. Chen was presented before the NASA Research Advisory Committee on Fluid Mechanics at JPL on May 6, 1965.

PLASMA DIAGNOSTICS
NASA Work Unit 129-01-07-01
JPL 329-11401-1-3832

LASERS

A giant-pulsed 100 Mw laser has been purchased and preliminary experiments have begun to determine the feasibility of using the laser to measure both the plasma electron density and velocity. The velocity will be measured using two techniques: measurement of the doppler shift of the laser radiation (because of the plasma motion), and by producing a local electrical breakdown in the plasma using a focused laser beam and later time-of-flight measurements of the ionized plasma element produced by the initial breakdown. The latter of these techniques is being tried first. Breakdown in a cold gas (argon at 300°K) has been achieved in a focused laser beam of 50 Mw. The magnitude of the diffusion of the plasma formed in the breakdown is now being investigated and, on completion of the diffusion experiments, velocity measurements in both cold gas and plasmas will be made in supersonic jets at ambient pressures of from 10^2 to $10^3 \mu$ in a vacuum tank. These experiments will be concluded in the first half of FY 1966. In the second quarter of FY 1966, the laser diagnostics using doppler shift will be started. Both laser techniques will be compared with the magnetic velocity probe.

Electron densities will be measured by monitoring Thomson scattering perpendicular to a laser beam in a partially ionized gas. The scattering experiment will first be conducted with a stabilized stationary arc in a discharge tube. If the preliminary scattering experiment in the discharge tube proves to be successful, the technique will be used to measure electron density gradients in and adjacent to a shock front in a partially ionized gas.

MAGNETIC VELOCITY PROBE

The shock tube study has been delayed approximately 6 mo because of a delay in the delivery of a test section to the Aerodynamics Facilities Section at JPL. Preliminary experiments with the shock tube (operated by the Aerodynamics Facilities Section) will be started in the first quarter of FY 1966. The effects of square wave heating of the probe elements, magnetic field configurations, and probe geometry will be emphasized and the results will be compared with steady-state tests conducted in a plasma vacuum facility using a steady plasma source.

MICROWAVE DIAGNOSTICS

Extensive measurements in the plume of a MPD source have been made with the 24 gc swinging arm (Ref. 1), measuring both transmission and reflection. The results are summarized in Ref. 2. The capability of the 24 gc system (both fixed and swinging arm) has been extended to include the measurement of phase as well as transmission and reflection, thereby extending the electron density measurements to $7 \times 10^{11} \lesssim n_e \lesssim 7 \times 10^{13}$. All the components needed for the 90 gc system have been received, and assembly of the first fixed geometry system will begin in the first quarter of FY 1966.

LANGMUIR PROBES

Langmuir probes have been used to measure electron densities and temperatures in the plume of a MPD source. A technique has been worked out to eliminate the uncertainty because hot electrical insulators (in this case boron nitride) can act as additional collectors of current. The technique and experimental results are reported in Ref. 2. Probe measurements are still limited to flows where the probe can be cooled enough to prevent appreciable emission from occurring at the probe tip. In the first half of FY 1966, square wave heating of Langmuir probes will be initiated and measurements will be extended to higher pressures (where a departure from the simple Langmuir theory is to be expected). Data obtained from these high pressure experiments will be compared to microwave data, which should not be sensitive to the increase in pressure.

SPECTROSCOPIC DIAGNOSTICS

Spectroscopic measurements of the intensities of 12 argon II lines made with a Jarrel-Ash 0.5 m Ebert monochrometer were used to determine the electron temperature in a MPD plume by the relative line intensity method. Both direct and Abel inversion techniques were used to obtain average electron temperatures in the plume, and temperature profiles across the plume diameter. The results are reported in Ref. 2. Measurements of plasma electron temperatures produced by a number of different plasma sources will be conducted in FY 1966.

MASS SPECTROMETER

The measurement of electron recombination rates will be continued in FY 1966. At low electron temperatures, the dissociative recombination rate may be the dominant recombination mechanism. Because it is believed that this rate is controlled by the rate of production of molecular ions, the molecular ion production rate will be measured with the use of a mass spectrometer. The mass spectrometer has been purchased and delivery will be made in the first quarter of FY 1966. Measurements using the spectrometer will be started at the end of the first half of FY 1966.

PRESENTATIONS

Two papers titled, "Diagnostics Studies of an MPD Arc," by N. Nerheim and "Microwave Diagnostics," by A. Kelly were presented before the NASA Research Advisory Committee on Fluid Mechanics at JPL on May 6, 1965.

REFERENCES

1. Kelly, A. J., A Microwave Probe for Plasma Plumes, AIAA, 3, 372, 1965.

2. Kelly, A. J., Nerheim, N. M., Gardner, J. A., Electron Density and Temperature Measurements in the Exhaust of a MPD Source, AIAA Second Annual Meeting and Technical Demonstration, San Francisco, California, July 26-29, 1965.

CONTINUUM FLUID DYNAMICS
NASA Work Unit 129-01-09-01
JPL 329-10201-1-3270

STABILITY OF POISEUILLE FLOW

The study of the hydrodynamic stability of viscous pipe flow is being conducted to show how finite amplitude fluctuations develop into turbulence. Disturbances were introduced into an otherwise steady flow by the oscillatory motion of deflection blades located near the pipe wall. As many as 12 simultaneous hot-wire signals describing the three components of velocity were recorded for various streamwise positions, frequencies, etc. Data acquisition was completed in February before Professor Komoda's return to Japan. Analysis of the records is being carried out, and a report will be published.

VELOCITY PROFILE IN LIQUID HELIUM

The flow of superfluid helium through a round tube is considered. An analysis of the curvature of the velocity profile at the flow centerline was made according to three of the available superfluid helium theories. Two of the theories, Lin's and the Görter-Mellink theory, predict a parabolic profile. However, the Hall-Vinen vortex theory predicts a profile with higher power terms. Therefore, the measurement of this quantity, a feat more readily possible than the measurement of the entire profile, has a chance of giving a conclusive result.

Little progress on the experiment has been made. The tranducer was lacking in sensitivity. Moreover, it performs erratically at liquid nitrogen temperature. Intensive effort is being made to perfect or replace the transducer so that measurements can begin.

WAKE STABILITY AND TRANSITION

Precision measurements of the hydrodynamic stability of the wake behind a two-dimensional object at Mach 3.7 are nearly complete. A thin plate spanning the width of the JPL supersonic wind tunnel produces a laminar wake. Sinusoidal disturbances of controlled frequency and amplitude are introduced into the wake by a method described in Ref. 1. A hot-wire anemometer measures the streamwise fluctuation growth rate and velocity of propagation. A Pitot tube measures the mean flow profile.

The geometry of the flow corresponds closely to that considered theoretically by Gold (Ref. 2 and 3). Figure 1 compares the predicted and measured amplification rates; the notation is Gold's. The ordinate represents the time rate of growth of a fluctuation. The abscissa is the wave number, which is approximately proportional to the frequency of the fluctuation. ΔT denotes the wake centerline-to-edge temperature difference divided by the edge temperature. The agreement of experiment with appropriate curve is quite good. Also shown are the measurements by Sato and Kuriki of a two-dimensional wake at incompressible speeds (Ref. 4). It follows that the two-dimensional stability theory is quite reliable in the range of ΔT considered here.

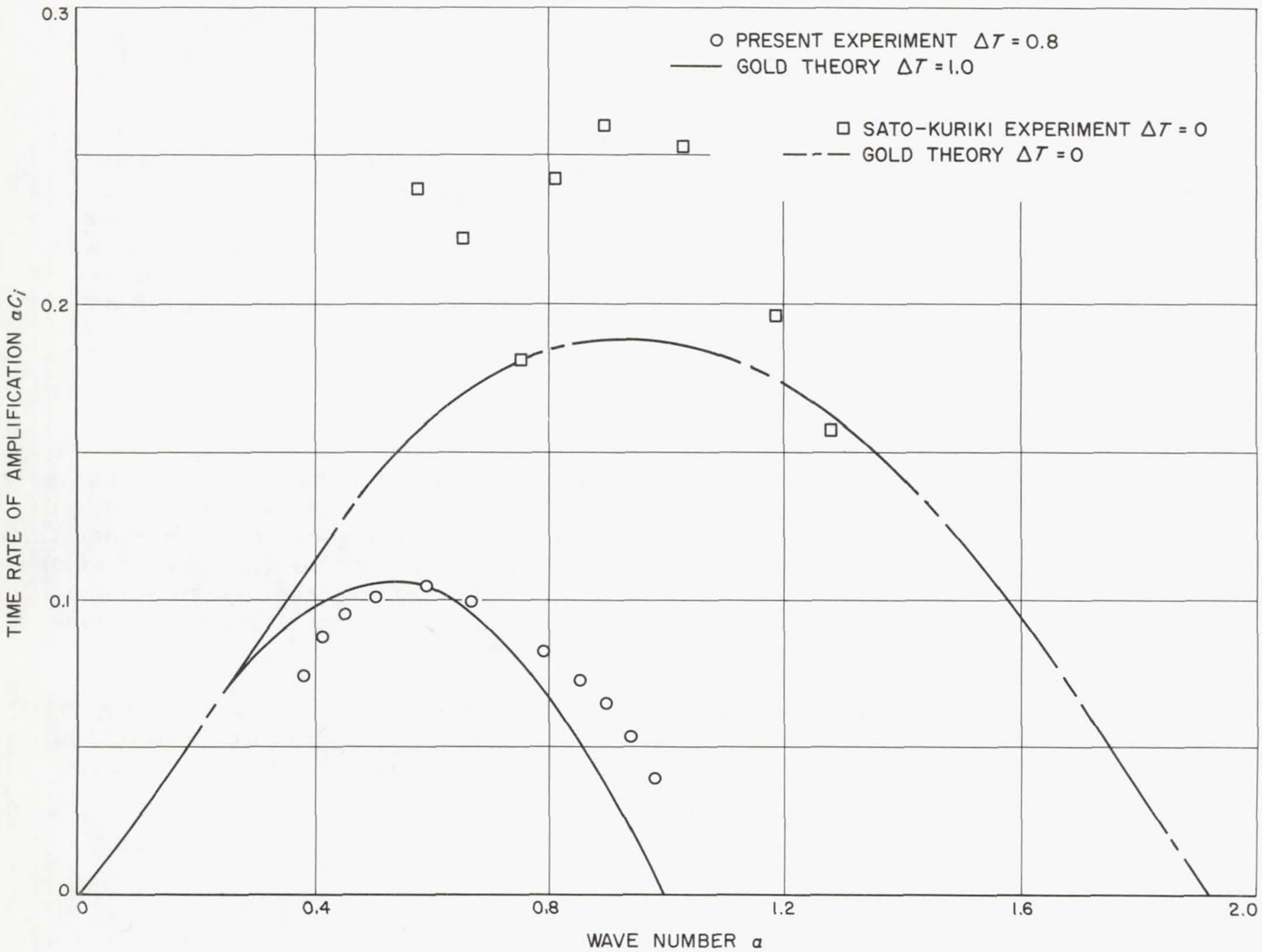


Fig. 1. Experiment and theory compared

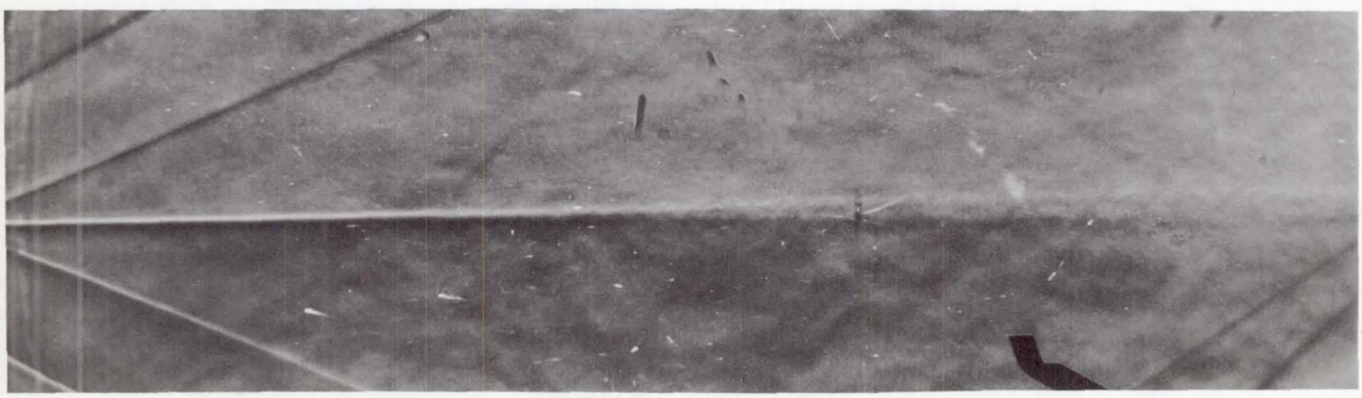


Fig. 2. Wake of thin plate (M_1 " 2.40)

The mechanism of wake transition is now being considered. Sato and Kuriki have shown that at subsonic speeds the wake transition occurs by amplification of naturally present disturbances into a vortex street, which in turn develops three-dimensionality and turbulence. The process is apparently different at supersonic speeds. Figure 2 shows an instantaneous photograph of a transitional wake. The hot wire confirms the absence of a vortex structure. Small-scale three-dimensional instability will be studied.

Present work is aimed at completing the details of the stability experiment, at measuring the axisymmetric wake stability, and at understanding the actual transition mechanism in supersonic wakes.

Several aspects of the above work were described at a seminar presented at the University of Southern California in May 1965.

BASE PRESSURE AND SEPARATED FLOW

Study of the flow separation and reattachment over a rearward-facing step at supersonic speeds has continued. Activity during the reporting period centered on data acquisition. About 72 Mach number-Reynolds number combinations were tested for Mach numbers between 2.0 and 4.5 and Reynolds numbers between 0.2 and 2.0×10^6. In each case, 30 or more pressures were recorded and schlieren photographs were taken. Sometimes titanium dioxide was used for examination of the reattachment pattern.

A variety of lip-shock and reattachment-shock configurations and diverse types of pressure distribution were found. In one case, a pressure distribution with a distinct overshoot was recorded. The strength of the lip shock is estimated to be far greater than is commonly believed.

The coming experiments will pertain to the flow behind the base of a symmetrical wedge. Other measuring instruments such as hot-wire anemometers and Pitot tubes will be brought into use in continuing studies of the rearward-facing step.

STABILITY OF LAMINAR COMPRESSIBLE BOUNDARY LAYER AT SUPERSONIC AND HYPERSONIC MACH NUMBERS

In the continuing study of the stability of the cooled laminar boundary layer, emphasis has been placed on the finite Reynolds number case. The results have been reported in detail in Ref. 5 and 6; Fig. 3 is taken from Ref. 5. The values of the cooling parameter, $\theta_w = 0.50, 0.10$, and -0.10, correspond to $T_w/T_r = 0.651, 0.249$, and 0.048, where T_ω is the wall temperature and T_r is the adiabatic wall temperature. $\beta\gamma/U^2$ is the dimensionless frequency. The figure indicates that the effect of cooling is to decrease the Reynolds number range (i.e., streamwise length) over which the flow is unstable, but to increase the amplification rate. These effects nearly cancel each other, as shown by the upper curve of Fig. 4. That curve represents the streamwise-integrated growth of disturbances introduced throughout the boundary layer up to the station where $R = \sqrt{Re_x}$ is 1500. It is seen that cooling has

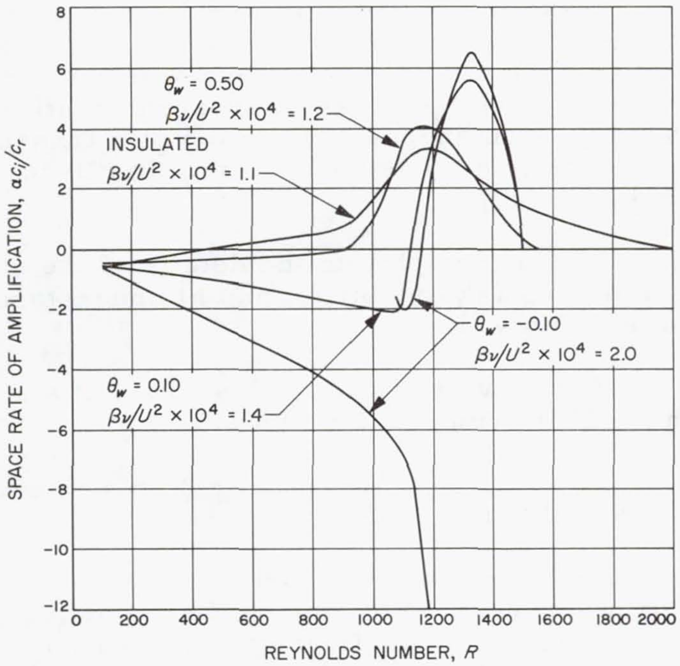


Fig. 3. Amplification rate of the most unstable frequency at R = 1500 vs Reynolds Number for the insulated and cooled boundary labels

little affect on the overall fluctuation growth. The lower curve describes a similar result except that the disturbance is assumed to enter the boundary layer at R = 100 (i. e., ahead of the neutral point).

In the earlier computations, the inviscid solutions are not necessarily unique. Attention was directed to whether each of the solutions corresponds to a separate solution at finite Reynolds numbers, or whether the introduction of finite viscosity makes the solution unique. For sufficiently large R, the eigenvalue diagrams are the same type as the inviscid solutions, thereby demonstrating that the inviscid solutions are indeed the infinite Reynolds number limit of the viscous solutions.

An attempt to experimentally verify certain predictions of the calculations, such as the multiplicity of instability modes, is planned. Techniques developed for the wake stability experiment will be used.

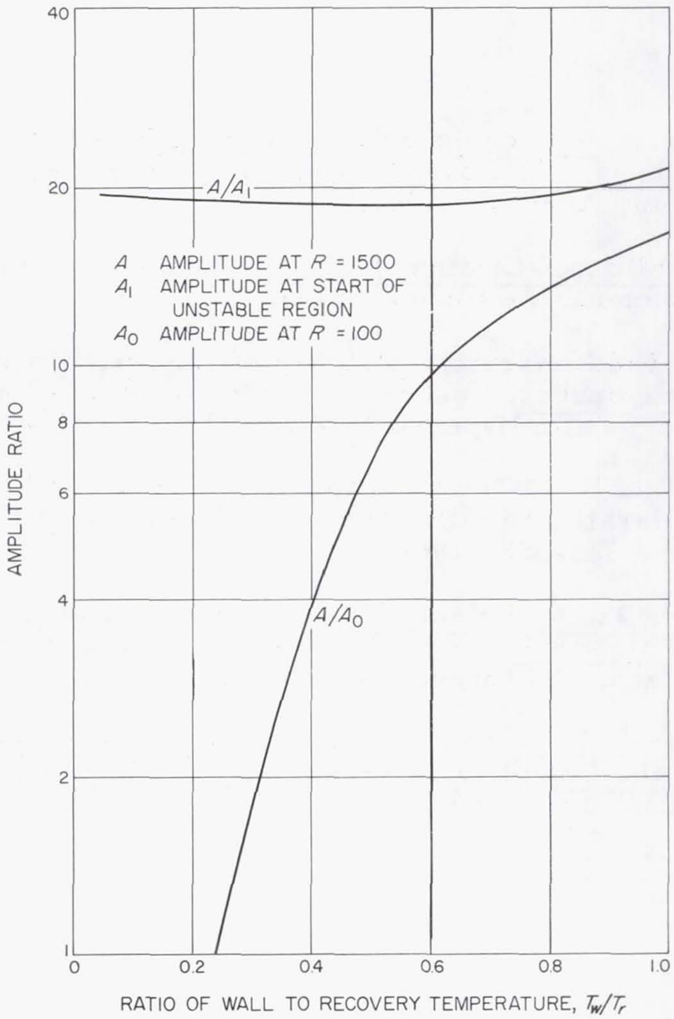


Fig. 4. Effect of boundary-layer cooling on the overall amplification of fixed-frequency disturbances at R = 1500

REFERENCES

1. Kendall, J. M., Jr., A Technique for Producing Small Disturbances in Supersonic Wake Flows, SPS 37-32, Vol. IV, p. 228, Jet Propulsion Laboratory, Pasadena, California, April 30, 1965.

2. Gold, Harris, Stability of Laminar Wakes, thesis, California Institute of Technology, Pasadena, California, 1963.

3. Lees, Lester, and Gold, Harris, Stability of Laminar Boundary Layers and Wakes at Hypersonic Speeds, paper presented at International Symposium on Fundamental Phenomena in Hypersonic Flow, Buffalo, New York, June 1964.

4. Sato, H., and Kuriki, K., "The Mechanism of Transition in the Wake of a Thin Flat Plate Placed Parallel to a Uniform Flow," Journal of Fluid Mechanics, Vol. 11, Part 3, pp. 321-352, 1961.

5. Mack, L. M., The Finite Reynolds-Number Stability of the Cooled Laminar Boundary Layer at $M_1 = 5.8$, SPS 37-31, Vol. IV, pp. 241-244, Jet Propulsion Laboratory, Pasadena, California, February 28, 1965.

6. Mack, L. M., Inviscid Eigenvalues and the Reynolds Number Dependence of the Eigenvalues of the Complete Laminar Stability Equations, SPS 37-32, Vol. IV, pp. 222-226, Jet Propulsion Laboratory, Pasadena, California, April 30, 1965.

PLASMA HEAT TRANSFER
NASA Work Unit 129-01-09-04
JPL 329-10701-1-3831

EFFECT OF MAGNETIC AND ELECTRIC FIELDS ON HEAT TRANSFER

Installation of power cables to the Building 107 test area has been completed. Experiments pertaining to the influence of electric and magnetic fields on heat transfer from ionized gas flows are to be conducted at this location. An electromagnet has been properly oriented and mounted on the thrust stand. The vacuum duct with quartz windows to be used as part of this installation has been designed and fabricated. It is now being installed. Fabrication of a test stand to support the plasma generator and the installation of coolant lines, a gas supply line, and rotameters will be done later. It is anticipated that preliminary experiments with applied magnetic fields will be conducted during the second half of FY 1966.

INFLUENCE OF SWIRL ON HEAT TRANSFER

Experiments of heat transfer from ionized argon flows have thus far been limited to measurements of heat flux distributions to the electrodes of arc plasma generators, mixing chambers, nozzles, and diffusers pending the completion of the Building 107 test facility. Significantly higher heat fluxes have been found to occur in the convergent part of a convergent-divergent nozzle for swirling flows than for flows without swirl (Ref. 1). Swirl is often introduced into arc heads to improve performance. To more easily evaluate the influence of swirl on fluid dynamic parameters that affect heat transfer, tests are being conducted of argon flows at room temperature in conjunction with the ionized gas flow tests. Cold flow tests conducted in the apparatus without electrodes present, as shown in Fig. 1, indicate that the ratio of the tangential velocity to axial velocity is very high in the convergent part of the nozzle, as shown in Fig. 2. Furthermore, this velocity ratio decreases as the flow progresses through the nozzle. Because convective heat transfer is proportional to mass flux, this velocity ratio indicates that high heat fluxes would be expected in the convergent region when swirl is present. The tangential and axial velocity components were determined from temperature and static pressure measurements along the end wall and static pressure measurements along the nozzle wall. To compute the velocities, it was assumed that boundary layers were thin and that viscous forces and radial components of velocity were negligible. Velocity distributions upstream of the nozzle and along the nozzle are shown in Fig. 3. A more detailed discussion of these results is given in Ref. 2.

HEAT TRANSFER TO NOZZLES, MIXING CHAMBERS, AND DIFFUSERS

The next series of heat transfer tests will be started about the beginning of FY 1966 with two hohlraums in the mixing chamber and with the arc head located around a corner from the nozzle, as shown in Fig. 4. The hohlraums (one with a quartz window and one without a window) will be used to measure the thermal radiation from the gas. The electrodes are located so that the apparatus downsteam cannot view the arc. The dummy cathode shown in Fig. 4 contains pressure taps and was used for initial cold flow tests. These cold flow results show that (even though the gas was injected tangentially and, hence, a comparatively strong vortex existed in the cathode housing) there was no evidence of swirl after the gas had turned the

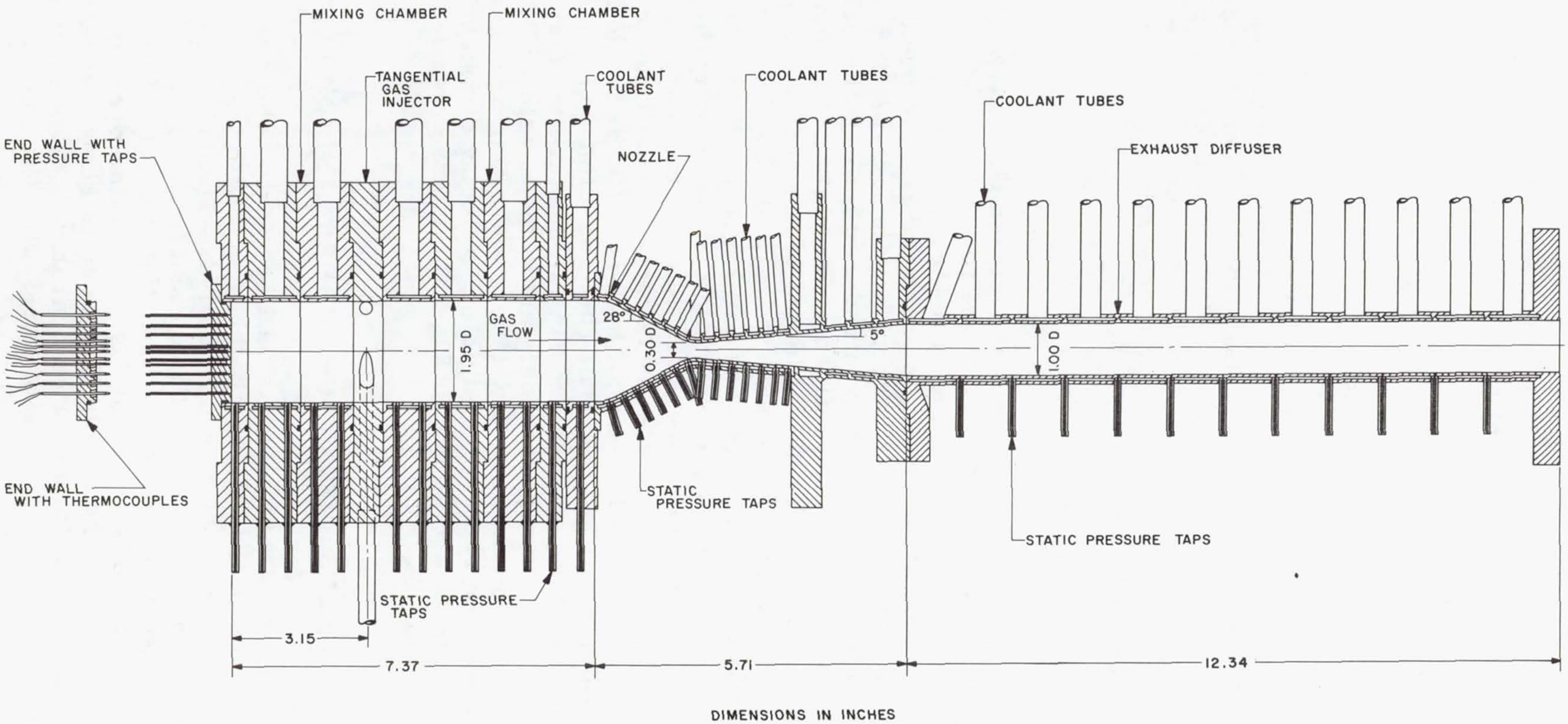


Fig. 1. Swirl flow test apparatus

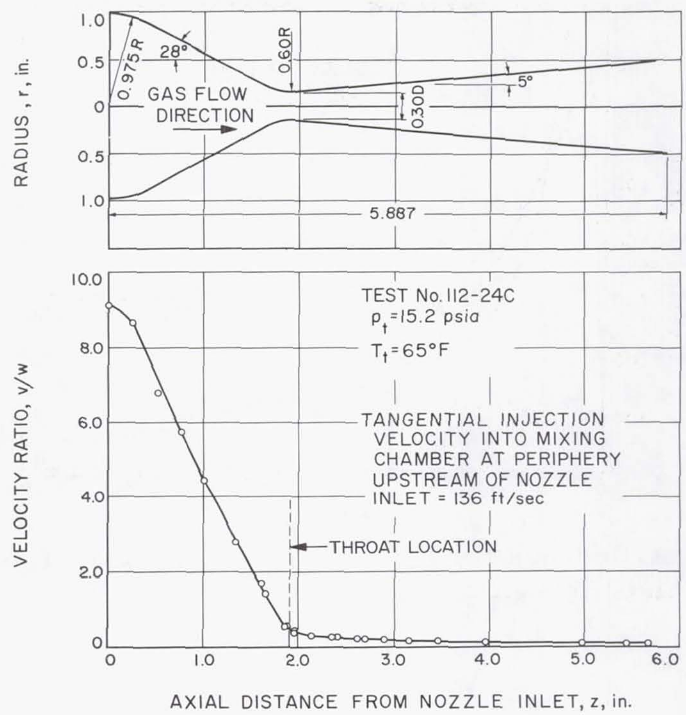


Fig. 2. Ratio of tangential to axial velocity distribution along 0.3 in. D_{th} nozzle for argon flow with swirl

corner. The dummy cathode has been replaced by a tungsten cathode without pressure taps, which will be used for the heat transfer tests that will follow. It is anticipated that spectroscopic and probe measurements will be made during some of these tests.

PUBLICATIONS, PRESENTATIONS, AND MEETINGS

The paper on the laminar boundary layer analysis (Ref. 3) that was discussed in the first Quarterly Progress Review for FY 1965 has been accepted for presentation at the 8th National Heat Transfer Conference, Los Angles, August 8-11, 1965.

The work of the Plasma Heat Transfer investigations was given before the NASA Research Advisory Committee on Fluid Mechanics at JPL May 6, 1965. This work was also discussed with Dr. Robert W. Graham, Head, Experimental Section, Lewis Research Center, and his associates.

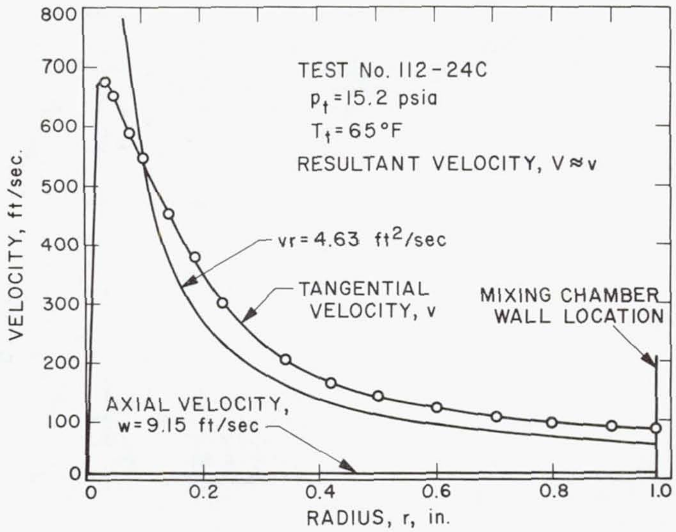


Fig. 3a. Velocity distributions for 0. 3 in. D_{th} nozzle for argon flow with swirl
a) At inlet through constant-diameter mixing chamber

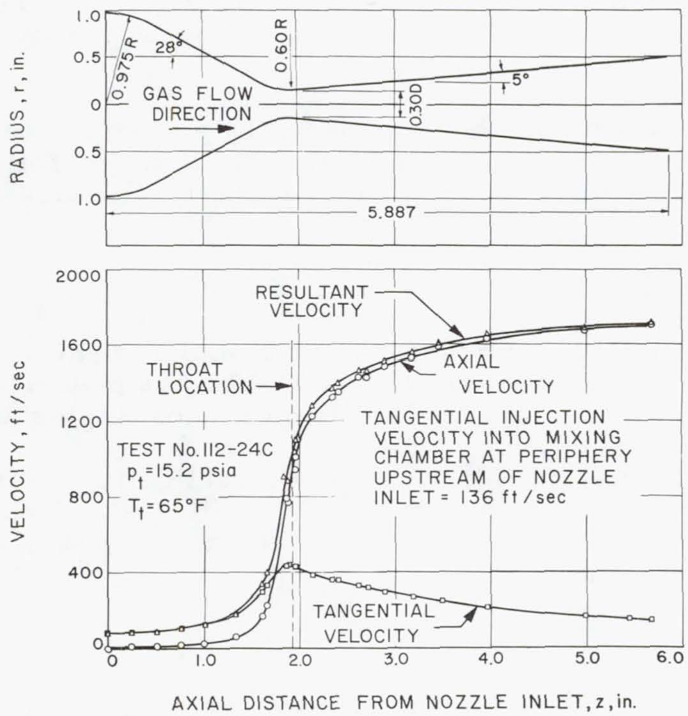


Fig. 3b. Velocity distributions for 0. 3 in. D_{th} nozzle for argon flow with swirl
b) Along nozzle

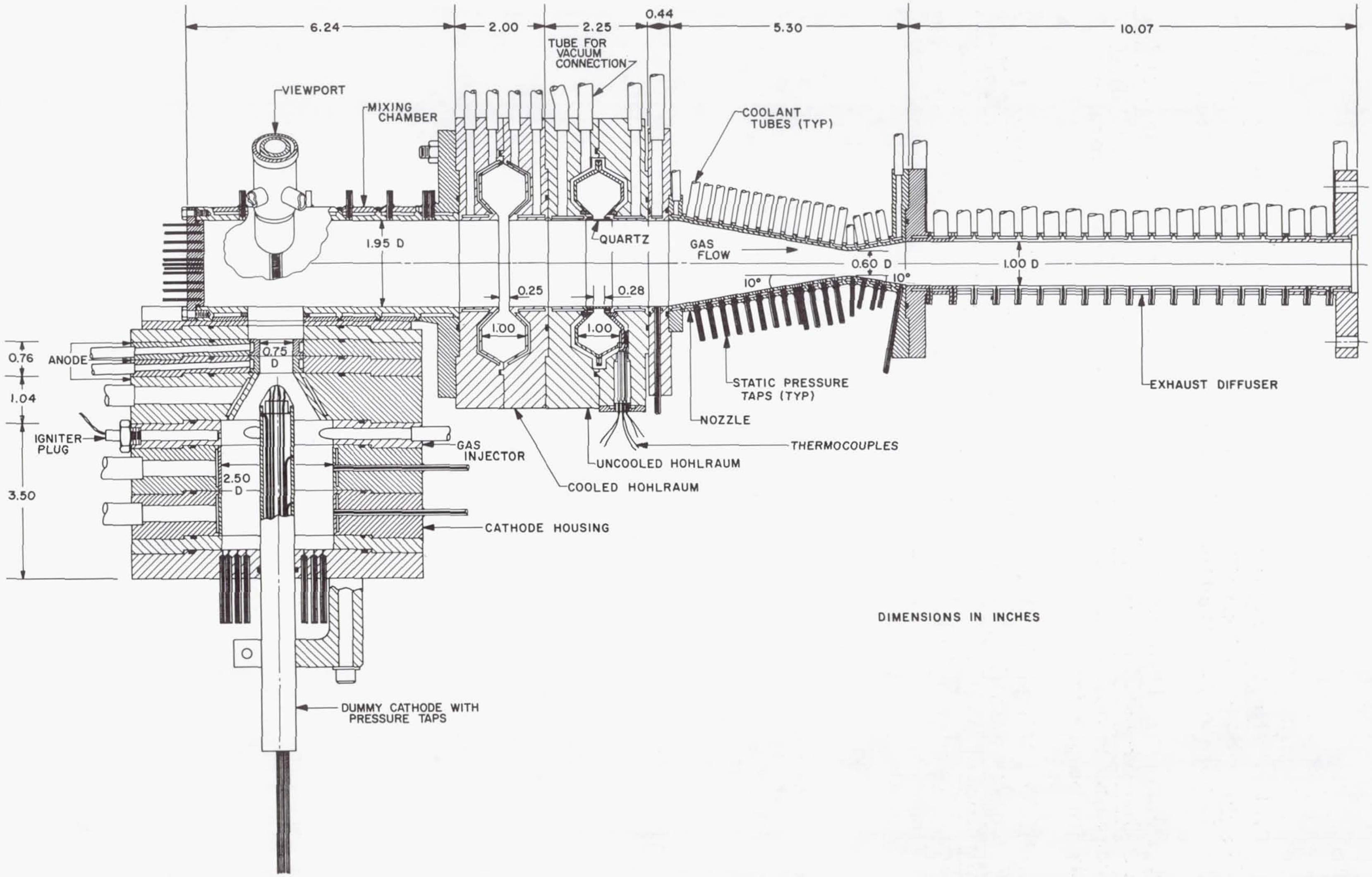


Fig. 4. Ionized gas heat transfer test apparatus

REFERENCES

1. Massier, P. F., Heat Transfer to Convergent-Divergent Nozzles from Ionized Argon, Space Programs Summary 37-24, Vol. IV, pp. 105-108, Jet Propulsion Laboratory, Pasadena, California, December 31, 1963.

2. Massier, P. F., Axisymmetric Steady Flow of a Swirling Compressible Fluid Through a Convergent-Divergent Nozzle Without External Heat Transfer, Space Programs Summary 37-33, Vol. IV, Jet Propulsion Laboratory, Pasadena, California (to be published).

3. Back, L. H. and Witte, A. B., Prediction of Heat Transfer from Laminar Boundary Layers with Emphasis on Large Free-Stream Velocity Gradients and Highly Cooled Walls, Technical Report No. 32-728, Jet Propulsion Laboratory, Pasadena, California, June 1, 1965. Also, ASME Paper No. 65-H-39.

RAREFIED GAS DYNAMICS
NASA Work Unit 129-01-10-01
JPL 329-10501-1-3270

EXPERIMENTAL STUDIES OF THE MERGED SHOCK-LAYER

A 5 to 20 kv electron beam is shot out through the nose of a spherical model, to be dissipated upstream in the wind-tunnel stagnation chamber. A small fraction of the gas atoms in the path of the beam experience inelastic collisions with the beam electrons, and the resulting fluorescence is detected by a highly collimated photomultiplier. The model and gun are mounted on the wind-tunnel traverse. Thus, axial fluorescence profiles can be obtained, and these are then related to the density distribution along the stagnation streamline.

All the equipment is mounted within the test section of the low-density wind tunnel; and, therefore, it must be remotely adjustable and vacuum tight. Construction of the equipment is essentially complete, and the alignment and spatial resolution of the photomultiplier system are now being checked. This is being done by suspending a fine tungsten wire through the electron beam. The wire is heated locally by the beam so that it serves as a light source of known axial dimension.

Photographs of the fluorescent beam-path show the expected increase in luminosity near the body surface. The first actual stagnation-streamline density profiles will be available shortly. It is hoped that the same measurement can be made over a wide range of Reynolds numbers and body surface temperatures.

SEEDED-GAS PLASMA STUDIES

Measurements Near a Plasma Shock Wave

Preliminary electron number density and temperature profiles have been measured in front of a flat disk in a supersonic seeded-gas plasma. The region of interest extended several body diameters upstream of the disk.

The initial phase of the experiment was a spectroscopic study of the flow region. Absolute intensity of the violet components of the diffuse series of cesium with energy levels of the atom in excess of 3.5 v were measured. The distribution of light intensity was measured along the axis and perpendicular to the axis of flow. The data taken perpendicular to the flow axis were used to give the radial intensity distribution by using a computer program for the Abel inversion. The results of this measurement imply that the electron temperature is constant throughout the flow and equal to 0.11 to 0.12 ev. In addition, the data imply that the electron density decreases radially as well as axially as the shock wave is approached.

Other spectroscopic techniques such as continuum and Stark broadening measuremens have been attempted. No positive results were obtained because the electron density (even at maximum seed concentrations) was too low, presumably because of recombination in the expansion, to give sufficient signal to be analyzed.

Because some lack of confidence exists about the interpretation of the spectroscopic measurements for electron density distribution near the shock, an electrostatic probe experiment was carried out. The probe study confirmed the electron temperature as measured by the spectrometer, but has yet to give a repeatable or accurate result for electron density. Further experiments will be attempted.

Free Jet Plasma in Aligned Magnetic Field

A large air-core solenoid magnet is being purchased to investigate the effect of an aligned magnetic field on the free jet plasma flow and on shock wave structure. The procurement requisition has specified a 10 kilogauss magnet. The power supply will not be ordered until the magnet's impedance has been specified.

NUMERICAL SOLUTION OF THE BOLTZMANN EQUATION

The aim of this phase of research is to obtain a numerical solution of the complete nonlinearized Boltzmann equation, using the numerical results from the solution of the Bhatnagar-Gross-Krook (BGK) equation as initial input to an iterative scheme.

The preliminary results obtained by applying the Romberg method to the evaluation of the five-fold integral show that the method is inefficient. The inte- scheme is being modified to include more of the qualitative features of the BGK gration solution; this should lead to a lesser number of individual computations, thereby reducing the size of the truncation errors.

LOW DENSITY SPHERE DRAG

Initial measurements of sphere drag in a free jet at very low tunnel stagnation pressures (< 0.5 mm Hg) have been performed. The simple pendulum technique can be satisfactorily used without the addition of a damping sphere. This arrangement reduces the tare drag and eliminates the damping fluid.

The preliminary data, when corrected for the drag of the supporting wire, do not follow the trend of previous measurements. The difficulty appears to stem from the operational characteristics of the very low density free jet. That is, the calculated effects of viscous dissipation are not realized in the laboratory. To take advantage, then, of the free jet as a testing medium, further work is required to evaluate the characteristics of the very low density free jet.

PUBLICATIONS AND SYMPOSIA

During the past 6 mo, a paper describing the operation of the seeded-gas facility was published in the Review of Scientific Instruments, January 1965. Space Programs Summary 37-32, Vol. IV, published April 1965, has a description of the spectroscopic measurements.

Dr. David Russell presented an invited lecture at the General Electric Company, Valley Forge, Pennsylvania, April 27, 1965, titled Remarks on the Structure of Shock Waves. An abstract by Dr. Russell and Professor Anatol Roshko, California Institute of Technology, on Shock-Wave Stengthening by Area Convergence, was submitted to the Fifth Shock Tube Symposium of the American Physical Society held at Silver Spring, Maryland, April 28-30, 1965.

Page Intentionally Left Blank

VORTEX INVESTIGATIONS
NASA Work Unit 129-01-11-01
JPL 329-11501-1-3831

A. GAS VORTEXES

The development of an optical instrument to be used for determining the transient mass flow rate of a high molecular weight gas in a mixture of high and low molecular weight gases discharging through the exit orifice of a vortex tube has been completed. The instrument was calibrated and used to measure the flow of Freon-13 (chlorotrifluoromethane) exhausting from the 4.50-in. diameter steel vortex tube. Experiments have been performed at various mass flow rates of hydrogen or nitrogen and Freon-13 in three basically different vortex tube configurations. The vortex type flows that can be generated in the laboratory retain about the same amount of heavy gas as would be expected if no diffusion were occurring. Because the gaseous-vortex-reactor concept requires a vortex type flow that can retain orders of magnitude more mass of heavy gas, it is concluded that a means must be found to generate a much higher strength vortex than is now possible.

Measurements of the mass of Freon-13 retained in the vortex tube compared to the mass that would be retained if no diffusion were occurring (diffusion coefficient $D_{LH} = 0$) are shown in Fig. 1. These measurements were made at four hydrogen mass flow rates, $\dot{m}_L$, and at each flow rate the Freon mass flow rate, $\dot{m}_H$, was varied between approximately 2 and 8% of $\dot{m}_L$. The significant features of Fig. 1 are that the retained mass ratio, $m/m_{D_{LH}} = 0$, is of order 1 and that no apparent trend is distinguishable as the hydrogen mass flow rate is varied.

The details of the distribution of Freon in a vortex type flow, as represented by the heavy-to-light gas mass density ratio, have been reported in a previous progress review. An example of those findings is shown in Fig. 2. If no diffusion had occurred, the density ratio, ρ_H/ρ_L, normalized with respect to itself at large radii, $(\rho_H/\rho_L)_\infty$, would have been constant with radius and equal to 1.0. Because this ratio is not constant, one can conclude that some diffusion does indeed occur. However, the alteration of the density ratio distribution appears to be a perturbation of the otherwise homogeneous binary flow and not the orders of magnitude change required by the gaseous-vortex-reactor concept.

Three technical reports have been written and are in the final stages of editing. The first covers the theoretical and experimental investigation of a binary vortex flow and includes the effects of inserting probes into this type of flow as determined by measuring the change in radial static pressure distribution. The second report covers the effects of mass flow rate and exit orifice diameter on the radial static pressure distribution in a nitrogen vortex flow. This report includes a comparison between the measured quantities and existing theories. The third report describes the mass retention measurements and summarizes the results of these measurements.

A technical report on similarity in confined, vortex flows has also been prepared. It is an attempt to determine (1) criteria by which vortex flows may be scaled and, also, (2) means by which experimental work of different investigators might be compared. The similarity model was derived from very simple considerations assuming a laminar, two-dimensional vortex flow. Experiments designed to

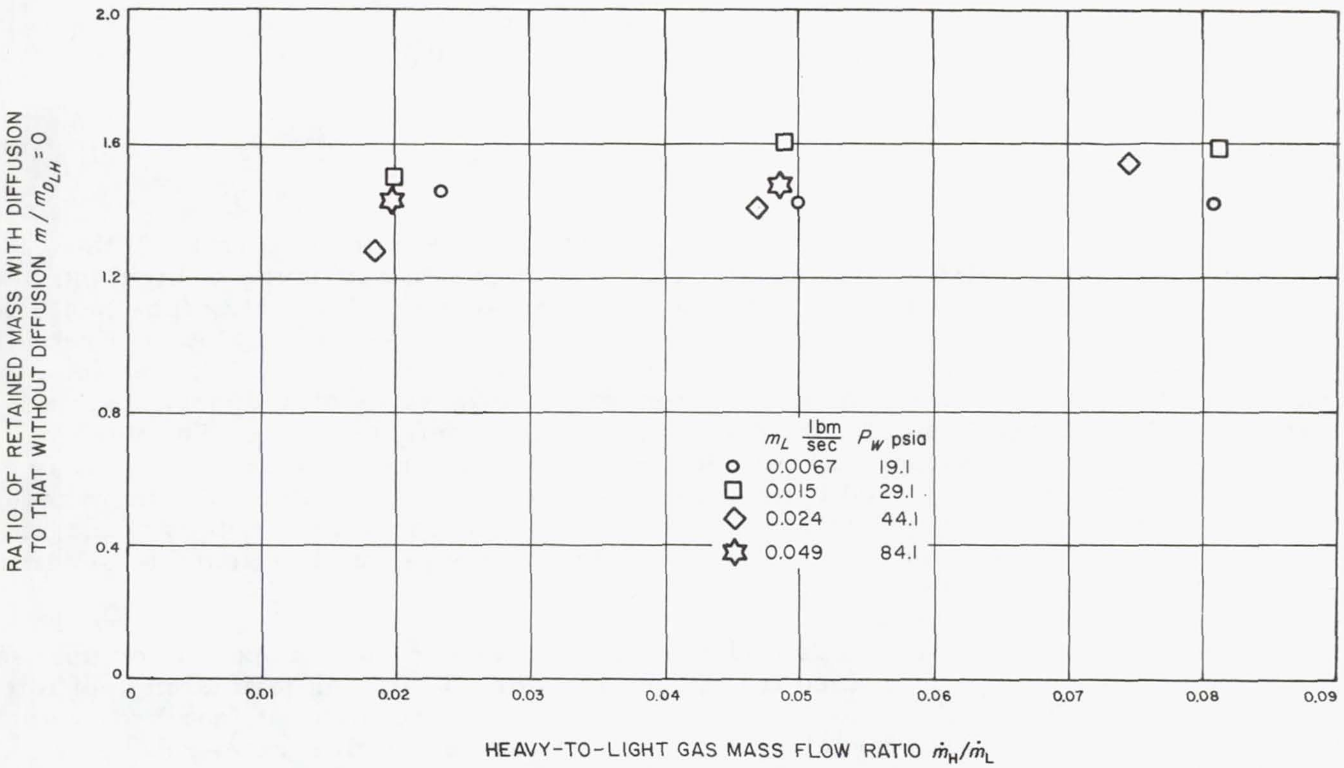


Fig. 1. Retained mass of heavy gas in binary vortex flow

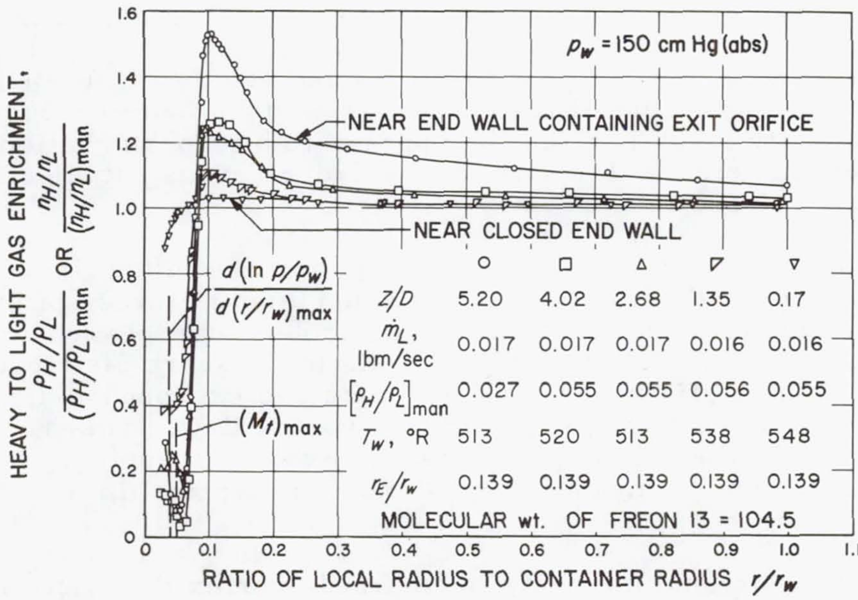


Fig. 2. Distributions of heavy-to-light gas mass density or concentration ratio in vortex containing mixture of hydrogen and Freon 13

test this theory were performed and indications are that the model is much too restrictive and not sufficiently realistic. These experiments were performed using gaseous nitrogen and gaseous hydrogen in separate tests in identically the same apparatus. Similarity conditions, as indicated by the model, were imposed on the tests that were then evaluated by comparing static end-wall pressure distributions. An interesting technique of obtaining similar end-wall pressure distributions was discovered, however, and this consisted of imposing the same static wall-pressure p_W on the two gases. Figure 3 shows the results of three such pairs of tests. This technique, which is not predicted by the theoretical model, nevertheless gave much better results.

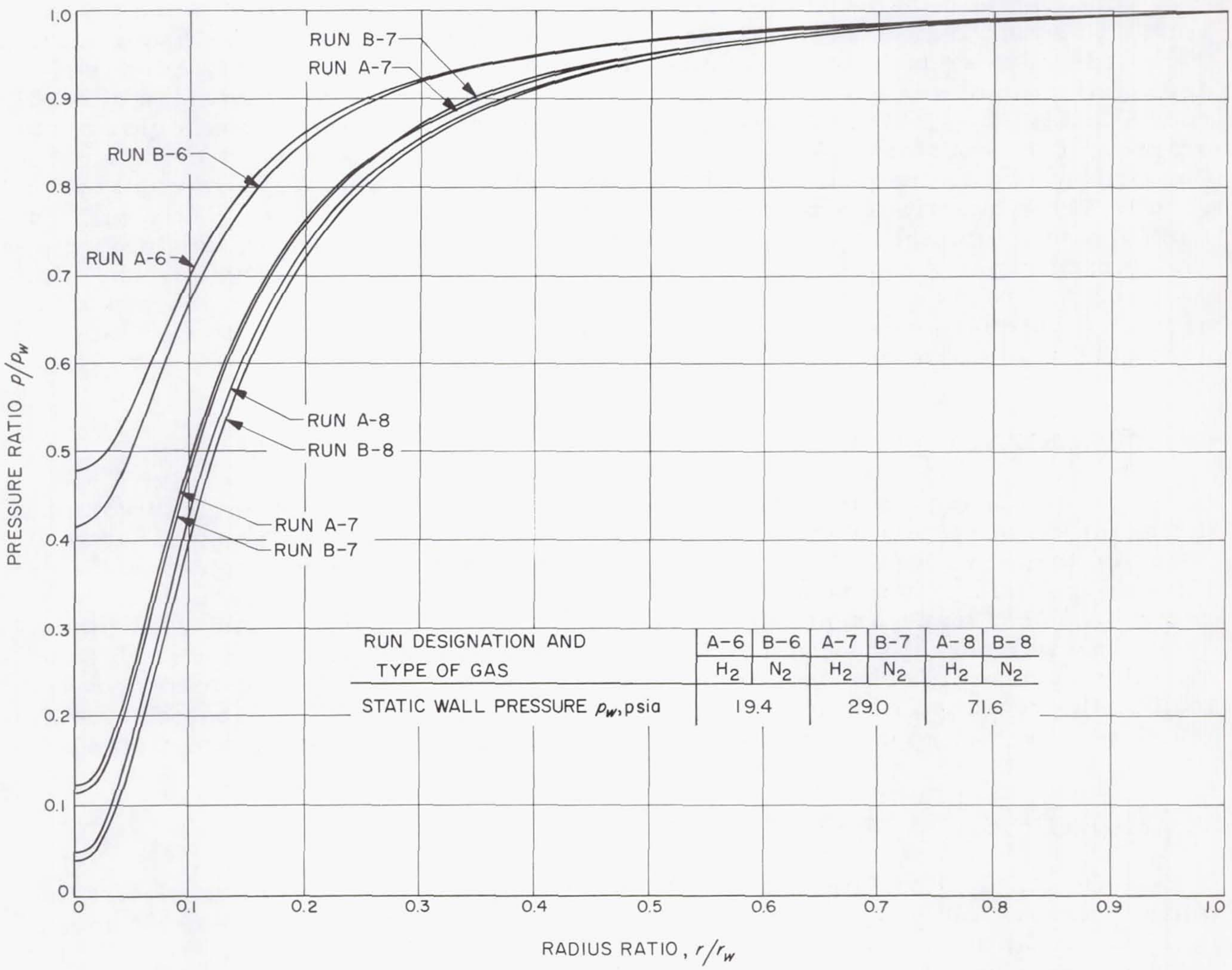


Fig. 3. Comparisons of pressure distributions between hydrogen and nitrogen run at equal values of static wall-pressure

B. WATER VORTEXES

A Space Programs Summary has been written and released concerning the effects of aspect ratio on the flow in a confined, jet-driven vortex tube. This work summarizes some of the effects of vortex length to diameter ratio that were observed in a water vortex. Aspect ratio, in addition to the relative exit-hole size of the vortex and the mass rate of flow per unit vortex length, did markedly affect the end-wall static pressure distributions observed in the vortex. Figure 4 shows a typical result; the vortex static pressure drop between the cylindrical wall and the vortex center line has been normalized for the static pressure at the cylindrical wall and plotted as a function of aspect ratio for several values of wall pressure. Sometimes an air core was present in the vortex, as noted. Flow visualization studies by dye injection into this same vortex apparatus had previously given some indication that differences in flow-field structure did occur as aspect ratio was varied. For small L/D, where the vortex is probably dominated by end-wall boundary layer effects, the flow appeared to be laminar, well-ordered, and radially stratified; core size in the vortex was relatively large. At large L/D, the flow appeared to be turbulent (not well-ordered) except in thin shear regions near the core; the vortex core tended to decrease in diameter with increasing L/D. An attempt to portray these effects is shown in Fig. 5, a series of drawings at different L/D adapted from color photographs. The experimental work carried out on the water vortex is being written in the form of two separate technical reports. The first report, which contains the results of the quantitative portion of the program and deals particularly with end-wall static pressure distributions, is complete and now in preliminary editing process. The second report, which will contain the results of the qualitative portion of the program and particularly flow visualization results, is still in the process of preparation. This latter report has been delayed because of the need to view and assess over 8000 ft of color motion picture film.

C. FUTURE ACTIVITIES

As a consequence of the discouraging results obtained in the gas vortexes for the retention of the mass of the high molecular weight gas and the small amount of diffusion that occurred, it was decided to end the entire vortex project at the end of FY 1965. During the first half of FY 1965, however, one experiment will be performed on a transparent tube that has provision for swirling end-wall injection as well as peripheral injection, adjustable L/D, and independent means of fluid injection at nine different locations. The experiments to be performed primarily include the retention of smoke in gaseous nitrogen. This is anticipated to be a minor effort because the apparatus has been fabricated and installed on a test stand.

D. MEETINGS AND PRESENTATIONS

Dr. E. J. Roschke and Mr. T. J. Pivirotto presented the results of the binary gaseous and water vortexes before the NASA Research Advisory Committee on Fluid Dynamics at the Jet Propulsion Laboratory, May 6, 1965. Mr. T. J. Pivirotto attended the AIAA Propulsion Joint Specialist Conference at Colorado Springs, Colorado, June 14-18, 1965.

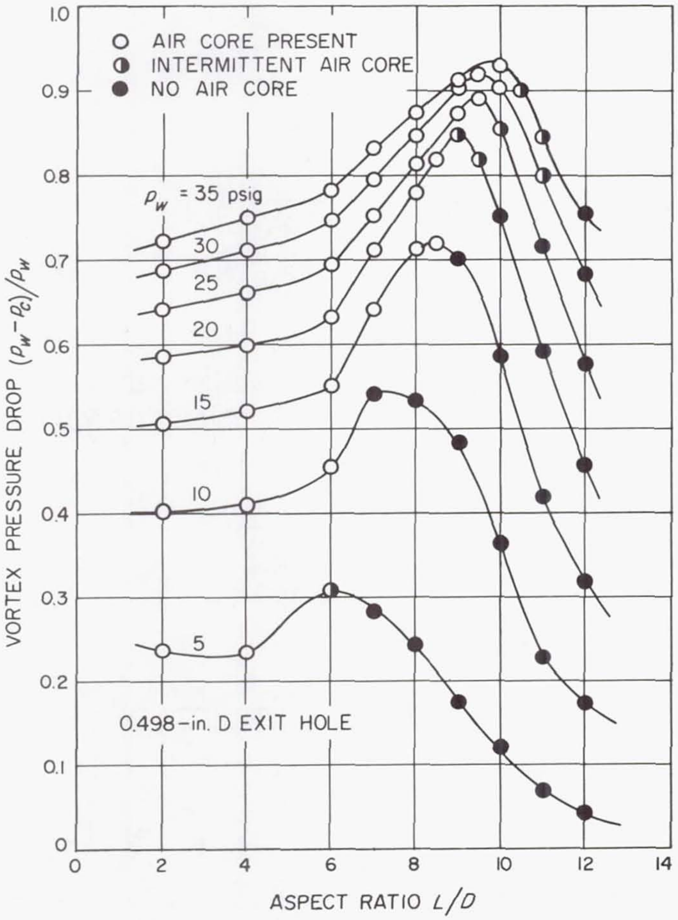
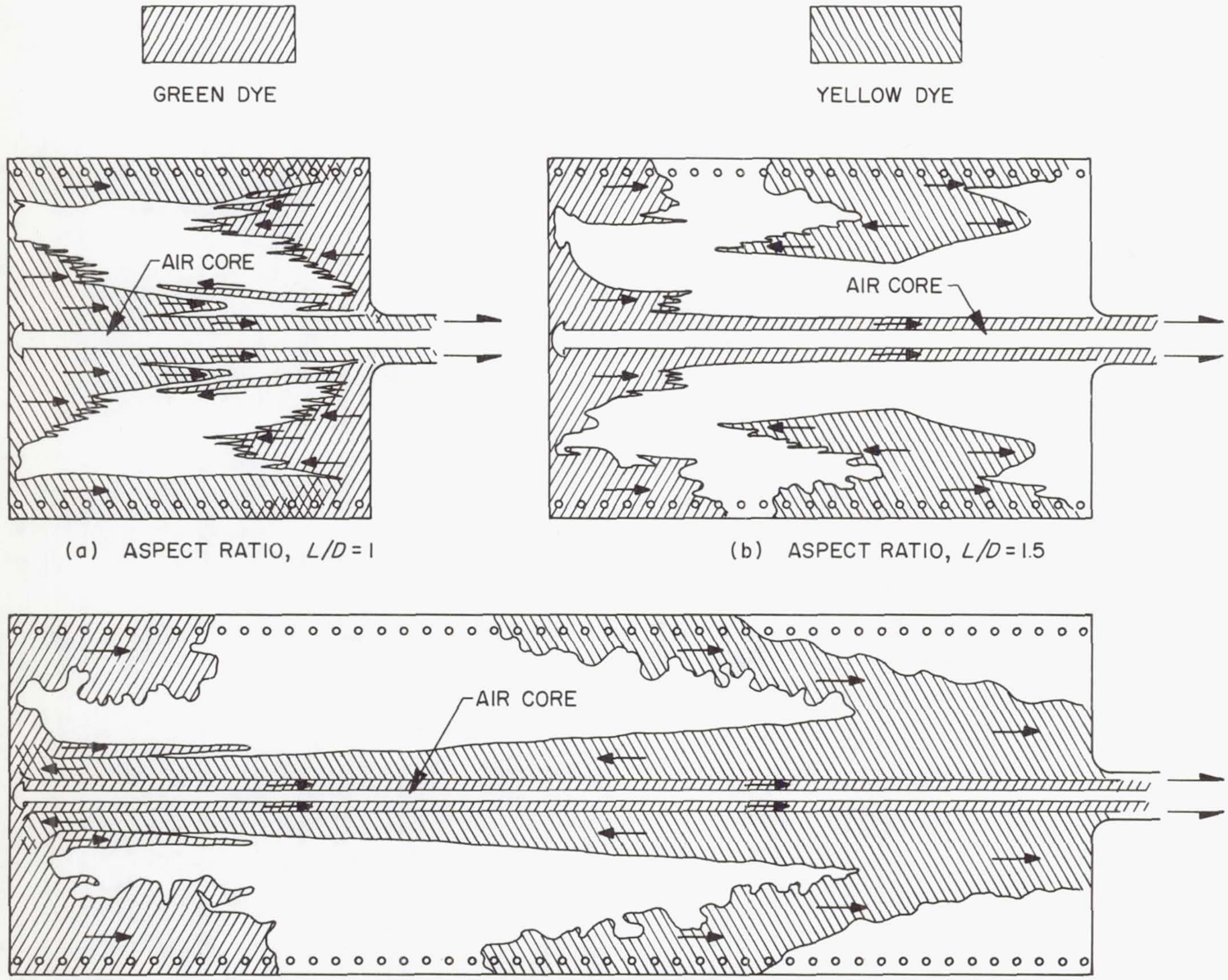


Fig. 4. Variation of vortex pressure drop with aspect ratio for various values of static wall pressure



(c) ASPECT RATIO, $L/D = 3$

Fig. 5. Dye studies in water vortex (drawings adopted from color photographs) with 0.5 in. exit hole, at static wall-pressure of 2 psig

HEAT TRANSFER AND FLUID DYNAMICS IN ACCELERATING AND DECELERATING FLOWS

NASA Work Unit 129-01-12-01
JPL 329-10401-1-3831

A. 45 DEG - 15 DEG NOZZLE

The nozzle that has a convergent half angle of 45 deg, a divergent half angle of 15 deg, and a ratio of the radius of curvature to throat radius r_c/r_{th} = 0.625 has been installed in the system. The dams have been repaired so no leakage occurs between the inlet and outlet lines of each passage. Tests with compressed air heated by the combustion of methanol to a stagnation temperature of 1500°R over a pressure range from 30 to 250 psia have been made. A comparison of the new data with the leaking dam data indicates, in particular, significant differences in the nozzle throat region where the variation in the heat flux to the wall is largest. Consequently, only the new data is considered usable. The new data is now being analyzed and some observations are worth noting.

Wall static pressure distributions for the 45 deg - 15 deg nozzle were given in Ref. 1 along with data for other nozzles that have been tested; a slightly condensed version of Ref. 1 has been submitted and accepted for publication in the AIAA Journal. Additional static pressure taps have been installed in the 45 deg - 15 deg nozzle and these reveal two regions where the wall static pressure unexpectedly rises locally other than in the shock-induced flow separation region that is associated with over expanded nozzle operation. These pressure rises occur in the inlet region and just downstream of the tangency between the circular-arc-throat and conical divergent section. In these regions the heat transfer data exhibit trends typical of those found in separated flow regions and, thus, the pressure rise may be enough to cause local flow separation and later flow reattachment. To indicate these observations, wall pressures and heat transfer coefficients are shown in Fig. 1. For the pressure scale chosen, the pressure rise in the inlet is not noticeable; however, the heat transfer behavior is observable because it is also just downstream of the throat. As seen in Fig. 3, there is a reduction in heat transfer at low stagnation pressure below that typical of a turbulent boundary layer. Similar trends were found (in Ref. 2) for the nozzle with a convergent half angle of 30 deg, a divergent half angle of 15 deg and r_c/r_{th} = 2.0.

B. CONSTANT PRESSURE GRADIENT NOZZLE

The fabrication of the constant pressure gradient nozzle has reached the stage where the final machining of the inner contour is now being done. The outer skin segments have been welded to the circumferential ribs to form the coolant passages. The pressure tap tubes, coolant passage inlet and outlet tubes, and boundary layer probe inserts have been welded in place. The passages have been checked for leakage across the dams, from passage to passage, and around the boundary layer probe and pressure tap tubes. The nozzle has been stress relieved.

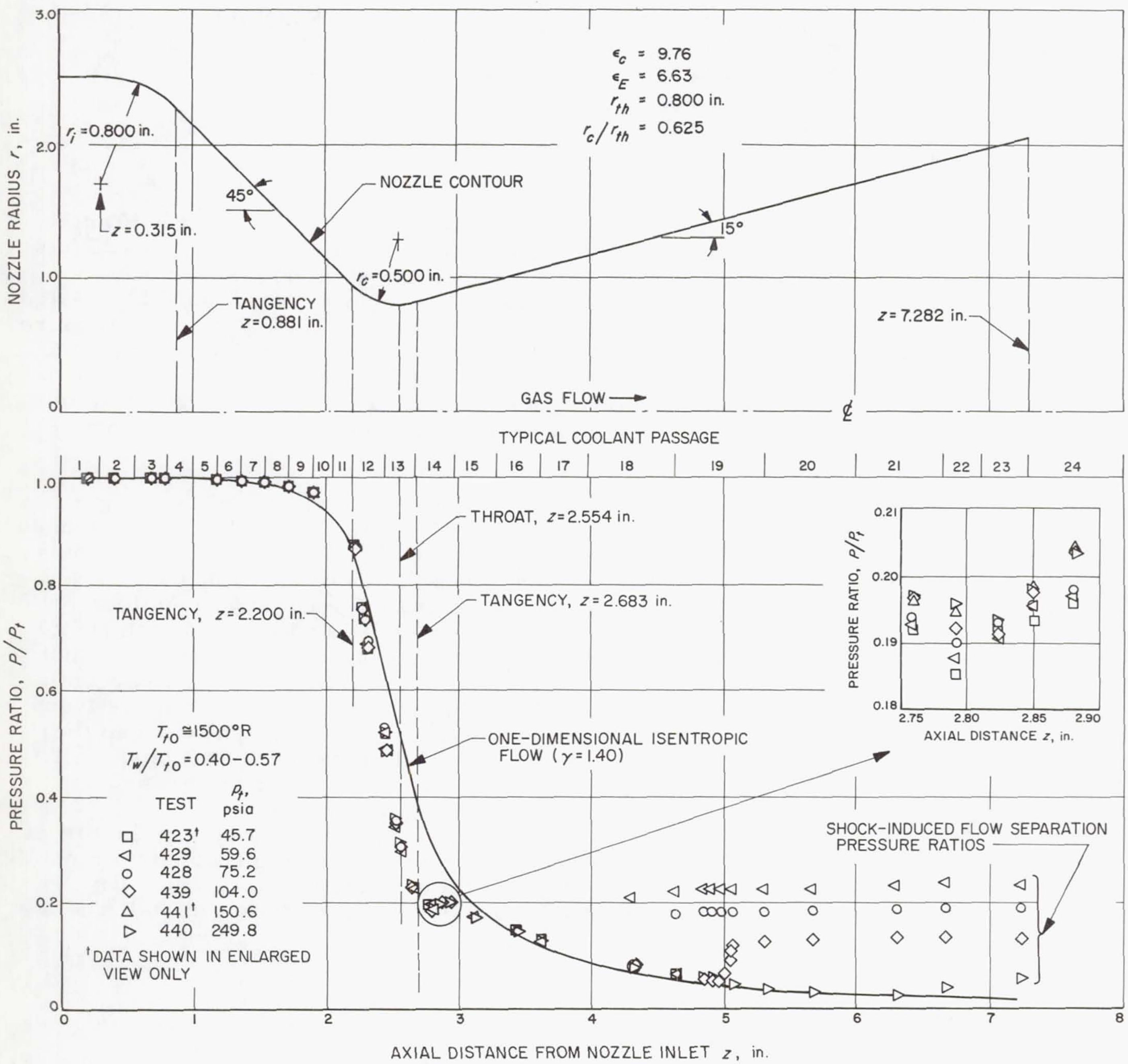


Fig. 1. Static to stagnation pressure ratios along 45 deg - 15 deg nozzle

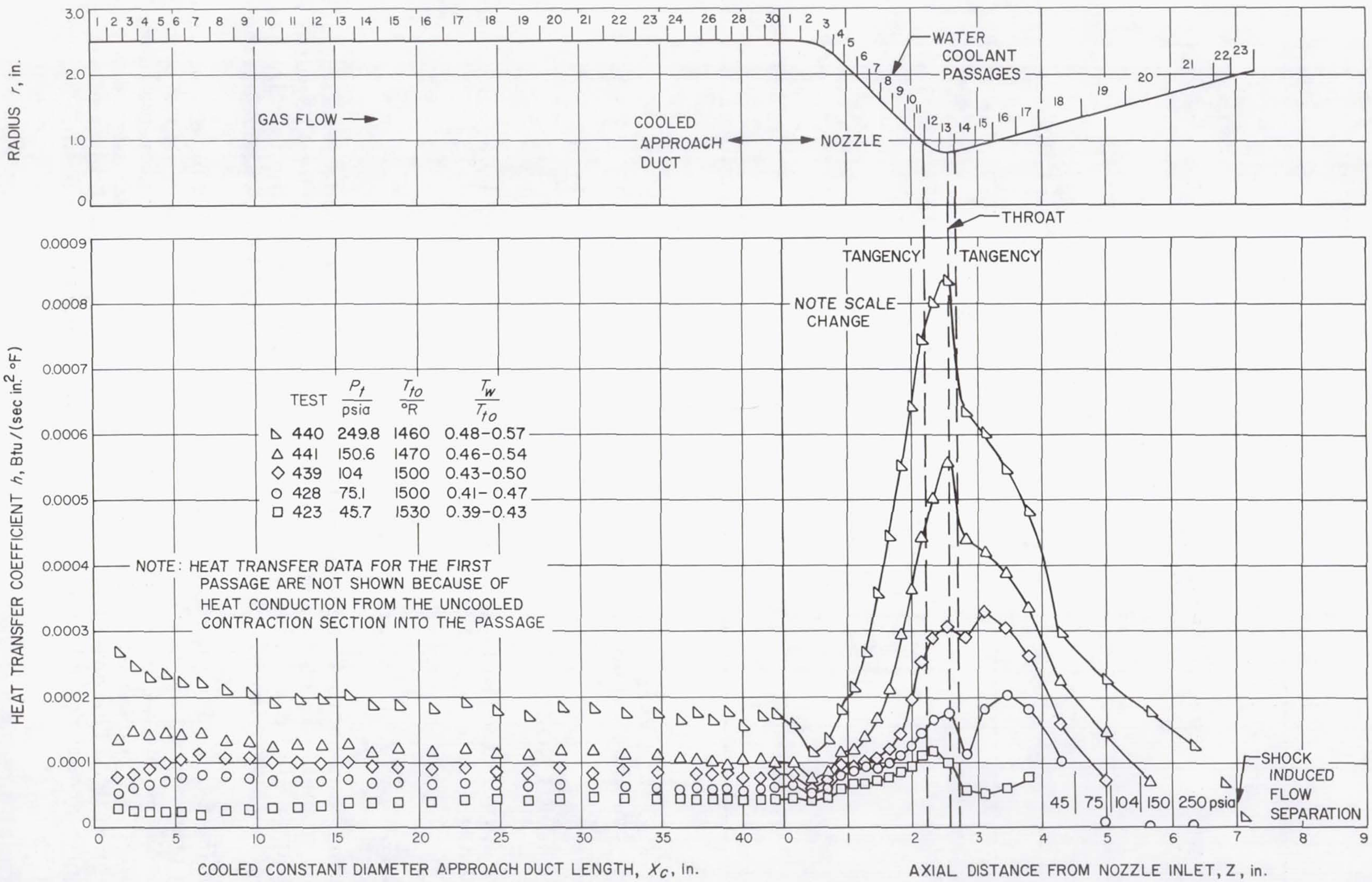


Fig. 2. Variation of heat transfer coefficient along duct and 45 deg - 15 deg nozzle

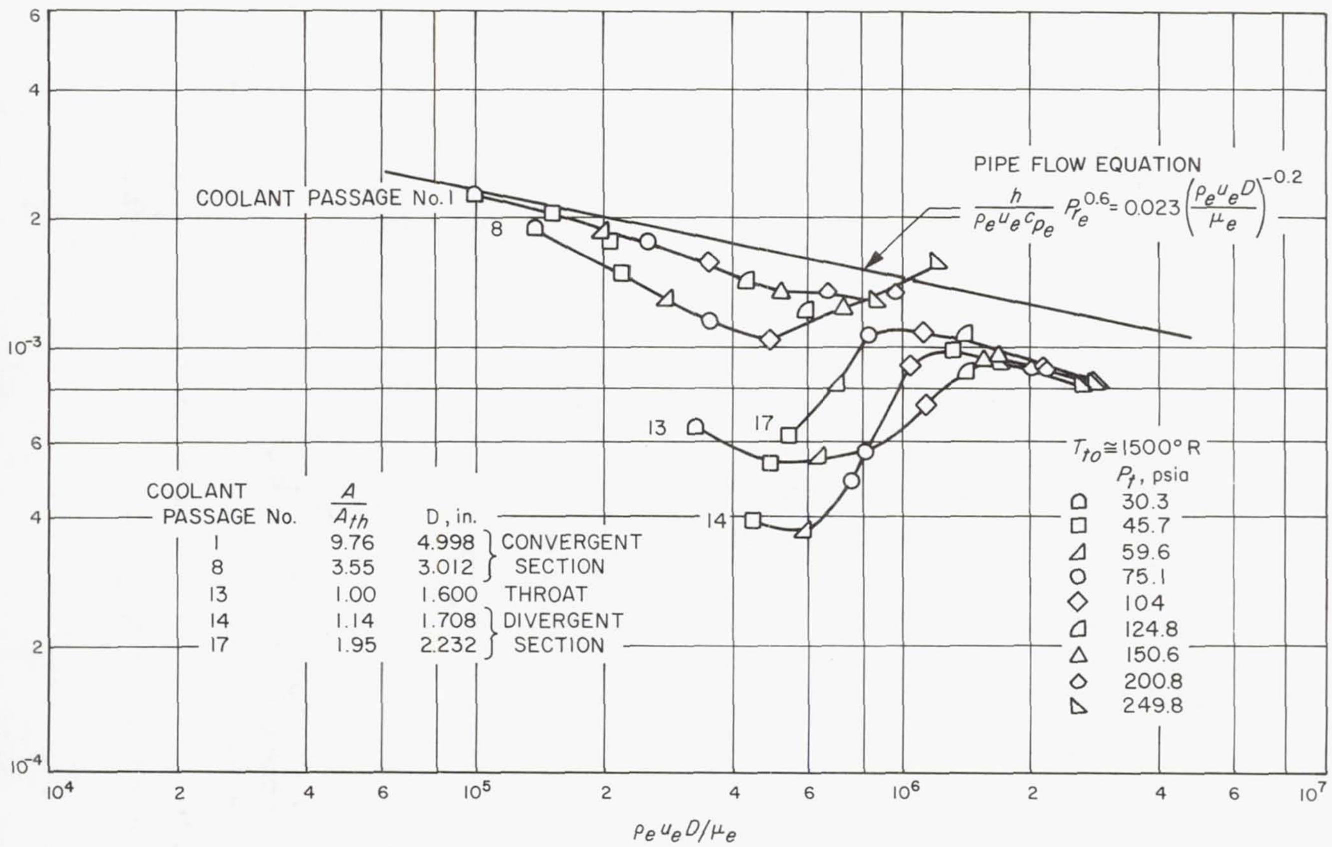


Fig. 3. Variation of Stanton-Prandtl number group at various coolant passages in 45 deg - 15 deg nozzle

C. 10 DEG - 10 DEG NOZZLE

Results of measured velocity distributions in the boundary layer obtained in the 10 deg - 10 deg nozzle are discussed in Ref. 3.

D. TEST FACILITIES AND INSTRUMENTATION

The piping, and controls necessary to use heated air directly from the JPL hypersonic wind tunnel, has now been completed and successfully checked out for test operations in the nozzle heat transfer facility. With this addition the facility has the capability of operation at temperatures up to 700 psia and 1500°R without combustion.

An existing 6-in. long cooled approach section, 5-in. in diameter, has been modified to accommodate four more boundary layer probes. It provides six circumferential probe locations at one axial position to study flow asymmetry upstream of the nozzle inlet. A combination pitot-tube temperature probe has been designed and one has been built. The outside diameter of the probe is 0.042 in. and will allow simultaneous pitot pressure and thermocouple measurements at the same circumferential location.

A pressure scanner that can accommodate 100 channels with 10 transducers is now available for use with this project. It has proven to be satisfactory and reliable and will be installed as soon as transducers now on order are available.

The instrumentation recording capability is being increased to accommodate 250 channels by connecting one additional Dymec recorder that is now used by the Plasma Heat Transfer Project. Connections are being made so that both Dymecs can be used interchangeably by both projects because they share the same test cell.

E. MEETINGS AND DISCUSSIONS

Dr. L. Back attended the NASA Fluid Physics Contractors Conference March 16-19, 1965, and exchanged information with both Dr. R. W. Graham, Head of Experimental Section and Dr. R. G. Deissler, Chief of the Fundamental Heat Transfer Branch, at the Lewis Research Center.

F. PLANNED ACTIVITIES FOR THE FIRST HALF OF FY 1966

Testing of the 45 deg - 15 deg nozzle will continue, with data to be obtained at nominal stagnation temperatures of 1000 and 2000°R and over a stagnation pressure range from 30 to 250 psia. Flow studies will be started to determine if the measured static pressure rise is enough to cause flow separation. Some data will be obtained with the hot air line. These data will be compared to the data that have already been obtained by burning methanol.

The fabrication of the constant pressure gradient nozzle should be completed.

The modified boundary layer probe section with six probe locations will be installed upstream of the nozzle to study flow asymmetries.

The 10 deg - 10 deg nozzle will be repaired, a few static pressure taps added, and the nozzle will be installed after the 45 deg - 15 deg nozzle tests are completed.

G. REFERENCES

1. Back, L. H., Massier, P. F. and Gier, H. L., Comparisons of Experimental with Predicted Wall Static Pressure Distributions in Conical Supersonic Nozzles, Technical Report No. 32-654, Jet Propulsion Laboratory, Pasadena, October 15, 1964; also to be published in AIAA Journal.

2. Back, L. H., Massier, P. F. and Gier, H. L., Convective Heat Transfer in a Convergent-Divergent Nozzle (Revision No. 1), Technical Report No. 32-415, Jet Propulsion Laboratory, Pasadena, Feb. 15, 1965 - also in Internation Journal of Heat Mass Transfer, Vol. 7, No. 5, pp. 549-568 (1964).

3. Back, L. H., Cuffel, R. and Gier, H., Boundary Layer Velocity Distributions in a 10° Half Angle Convergent-Divergent Nozzle, Jet Propulsion Laboratory Space Programs Summary No. 37-31, Vol. IV, pp. 169-174, Feb. 28, 1965.

Page Intentionally Left Blank

ELECTRO PHYSICS RESEARCH (129-02)

THERMIONICS RESEARCH
NASA Work Unit 129-02-01-07
JPL 329-21101-1-3450

A. NATURAL OSCILLATIONS IN CYLINDRICAL CESIUM DIODES

During this period, electrical oscillations of spontaneous origin were examined experimentally using JPL-built cesium diodes. The objective of these experiments is to better understand the physics of thermionic energy converters, especially to explain the spontaneous oscillations that can occur in cesium diodes. Enhancement of such oscillations by applying an external magnetic field is another objective.

Three glass diodes were built at JPL for the study of oscillations. Two of the diodes had cylindrical collectors that were 1/2 in. in diameter and 2 in. in length. The other diode had a cylindrical collector that was 0.25 in. in diameter and 0.654 in. in length. This small diode was constructed to examine the effects on the oscillations of interelectrode distance and of the temperature distribution along the filament. Although both nickel and tantalum were used as anode materials, no effects on the oscillations were observed because of the different materials. Each diode was operated in a temperature-regulated oven, and the cesium reservoir temperature was determined from the equilibrium oven temperature. Filament temperatures were determined with a pyrometer. The filament was directly heated from a half-wave rectified 60-cycle current source, and volt-ampere curves were obtained during the off periods of the heating current. Waveforms and frequency spectra of the oscillations were measured across a decade resistance box that was connected in series with the diode.

Oscillations were found to occur in the plateau part of the volt-ampere curves when the emitter temperature, T_E, and the cesium reservoir temperature, T_{Cs}, were such that nearly neutral emission was occurring at the emitter surface. The amplitude of the current oscillations, which was as large as the dc current, increased as the circuit resistance was decreased until a threshold value of resistance of the order of 1 ohm was reached. Below this value, no further change occurred in the oscillation. At this point, the maxima and minima of the oscillating current were measured, and the current density was determined using the effective emitter area. Such current densities were plotted as a function of the reciprocal of the emitter temperature as shown in Fig. 1. The double-valued (hatched) parts of the curves indicate the regions where oscillations occurred. The maxima of the oscillating current follow closely the theoretical S-curves, which are shown in broken lines. These lines were drawn for current densities that were obtained from the Warner-Rasor theory for a bare metal work function of 4.65. Three features of the results shown in Fig. 1 are:

1. Oscillations occurred within narrow temperature combinations of T_E and T_{Cs}, so that the electron current density, J_e, and the ion current density, J_i, were related to the mass of the carriers by:

$$J_e/J_i \approx \sqrt{m_i/m_e} \ .$$

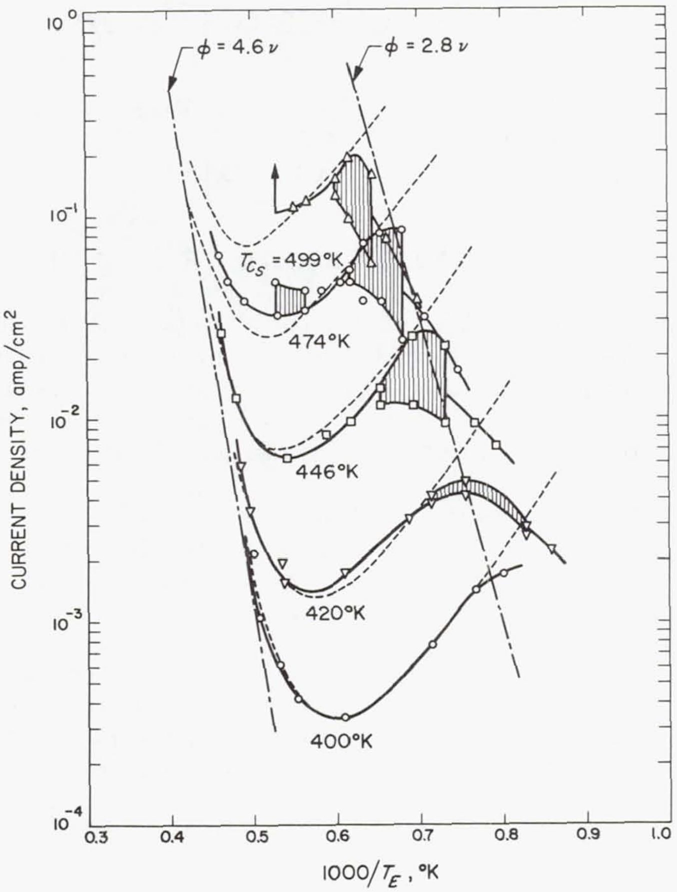


Fig. 1. Amplitude of oscillation

(W-Ta small diode)

The charge densities under such temperature combinations are neutral at the emitter surface.

2. Oscillations did not occur for very high or very low cesium reservoir temperatures. Large values of T_{Cs} result in a small mean-free-path for electrons, and this causes collisions between particles that disrupt coherent oscillations. When T_{Cs} is reduced, the current density reaches a value so that the space-charge minimum or maximum does not occur. It appears, therefore, that the formation of a collisionless space-charge is a required condition for the oscillations to exist.

3. Because the maxima of the current oscillations followed the theoretical line for temperature-saturated electron current, the peak-to-peak variation of the current can be explained in terms of a switching between two conduction mechanisms: one conduction mechanism operating at the maximum

value of the current, and another mechanism at the minimum value. The current conduction switches between the temperature-saturated value at its maximum and the space-charge-limited value at its minimum.

The variation of the depth of the potential minimum, which would have caused the observed fluctuation in current, was calculated to be of the order of 100 mv. Such a value is expected in a diode operated in a space-charge-limited mode. The results concerning the frequency of the oscillations indicated that the frequency is a function of the product of cesium pressure times interelectrode gap. Further investigation will be required to obtain more definitive conclusions concerning the frequency of the oscillations. Amplitude-modulated waveforms were observed, and were caused by the temperature distribution along the filament.

B. METAL-CERAMIC DIODE FOR USE IN AN APPLIED MAGNETIC FIELD

To study externally excited oscillations at elevated cesium reservoir temperatures up to 600°K, a metal-ceramic diode was proposed to be built. The design of a metal-ceramic diode having collectors in four identical segments was completed on contract to Electro-Optical Systems, Inc., Pasadena, California. Whether a metal-ceramic diode will be fabricated depends on the results that will be obtained on our glass diodes with an external magnetic field applied. Preliminary investigations during this period, together with work performed previously by another investigator at JPL, indicate that it may not be possible to excite the low-frequency magnetosonic oscillations in which we are interested. It is likely that the simplified theory of magnetosonic oscillations developed at JPL does not apply to the experimental diodes. Effects of a magnetic field applied to the plasma of a cesium diode operating in the arc mode are yet to be investigated.

C. CONSULTING WORK FOR THE SPACECRAFT POWER SECTION

The following consulting services were performed:

1. Technical evaluation of two proposals on low-voltage thyratrons.
2. Calculation of the internal impedance of a thermionic generator.
3. Design of a low-inductance strip line for a dc-dc converter.
4. Technical evaluation of various items for future research and development efforts in the spacecraft power section.

D. FUTURE PLANS

The possibility of exciting magnetosonic like oscillations will be investigated using glass diodes that have already been tested for spontaneous oscillations. Because we now have an additional glass diode in a smaller envelope, which enables us to wind a solenoid around the diode, external signals can be applied to excite oscillations. Results of these investigations will be reported at the International Thermionics Conference in London, September 1965, in addition to the results obtained so far.

An electron gun to be used with a proposed thermionic diode having a hot plasma emitter will be designed and tested. The design has already begun.

An analysis of spontaneous oscillations in cesium diodes will be made using a simplified model. Truncated velocity distributions for emitted electrons will be used in the analysis. It is hoped that we will be able to obtain a fairly simple mathematical analysis that incorporates all the various features of our interpretation of spontaneous oscillations in cesium diodes.

E. PUBLICATIONS

1. K. Shimada, Low-Frequency Oscillations in Cylindrical Cesium Diodes, 25th Physical Electronics Conference, Massachusetts Institute of Technology, Cambridge, Massachusetts, March 24-25, 1965.

2. K. Shimada, Self-Excited Oscillations in Cylindrical Cesium Diodes, JPL Space Programs Summary 37-33, Vol. IV (to be published).

3. K. Shimada, Excitation of Low-Frequency Oscillations in Cesium Diodes, submitted to the Institution of Electrical Engineers, United Kingdom, for presentation at the International Conference on Thermionic Electrical Power Generation, London, England, September 20-24, 1965.

PHOTOCHEMISTRY
NASA Work Unit 129-02-0 -02
JPL 329-21001-1-3260

A. REACTIONS OF ELECTRONICALLY EXCITED ATOMIC OXYGEN

The primary activity in this program has been a study of the reaction of $O(^1D)$ with hydrocarbons. The work has mainly been experimental, and has included the addition of gas chromatography as an analytical method.

The reaction of $O(^1D)$ with methane has been investigated by the technique of photolyzing mixtures of ozone and methane dissolved in liquid argon. From experiments completed to date the following facts have emerged:

1. The reaction of $O(^1D)$ with CH_4 is extremely fast, unlike the reported rates of $O(^3P)$ reactions. The activation energy is zero.

2. Major products are CH_3OH (50%), CH_2O (7%), and H_2 (6%), the yields being based on O_3 decomposed.

3. Addition of O_2 to the photolysis mixture reduces the photoreaction rate and increases the product yields by a factor of about 1.3. These observations suggest the presence of a scavengeable radical, probably CH_3.

A tentative mechanism for the reaction involves formation of hot CH_3OH by insertion of $O(^1D)$ into the CH bands of methane, as follows:

$$O(^1D) + CH_4 \longrightarrow CH_3OH^* \qquad \Delta H = -135 \text{ kcal/mole} \tag{1}$$

followed by either deactivation or decomposition of CH_3OH^*:

$$CH_3OH^* + M \longrightarrow CH_3OH + M \tag{2}$$

$$CH_3OH^* \longrightarrow CH_2O + H_2 \tag{3}$$

$$CH_3OH^* \longrightarrow CH_3 + OH \tag{4}$$

Further experiments are planned to determine if CH_3OH^* is, in fact, an intermediate in Reactions (3) and (4), as proposed in the mechanism. The method will be to vary the nature of the third body, M.

A second phase of this program will be the measurement of the relative rates of $O(^1D)$ with a series of hydrocarbons and also H_2. Of particular interest will be the relative rate of reaction with the CH bonds of ethylene compared with the rate of addition to the double bond.

Experiments are continuing on the pressure dependence of certain three body reactions of $O(^1D)$ in the gas phase at pressures up to 150 atmospheres. The object of this work is to demonstrate a high order pressure dependence for these reactions, which has been predicted on theoretical grounds.

B. REACTIONS OF ELECTRONICALLY EXCITED MOLECULAR OXYGEN

No new experiments have been carried out in this area because of a lack of available manpower.

C. PUBLICATIONS AND ORAL PRESENTATIONS

1. "Primary Processes in Ozone Photolysis," Space Programs Summary No. 37-31, Vol. IV. This material is now being prepared for submission to the Journal of Chemical Physics.
2. A chapter on "Gas Kinetics" for the Annual Review of Physical Chemistry, 1965, is now in press.
3. A paper titled The Reaction of $0(^1D)$ with Hydrocarbons will be presented at the International Conference on Photochemistry, Tokyo, Japan, August 25-28, 1965.

PLASMA PHYSICS RESEARCH
NASA Work Unit 129-02-03-03
JPL 329-20701-1-3280

A. THEORETICAL STUDY IN PLASMA KINETICS

Theoretical investigation on fundamental problems in plasma kinetic theory has continued. Work has been completed on calculating the high-frequency plasma conductivity using the plasma kinetic equation with dynamic shielding (Ref. 1). It was found that if the electron/ion temperature ratio is greater than the ion/electron mass ratio, there is a significant enhancement of the plasma resistivity resulting from the excitation of ion waves in the plasma. Because of the possible direct experimental observation of this two-temperature effect, a more accurate analysis based on the BBGKY hierarchy and using an operator method previously developed by Wu (Refs. 2, 3) would be worth pursuing. This work has been completed except for computer results. These numerical results will be completed shortly and a complete report finished during the next 6 mo period.

Two additional applications of Wu's operator method have also been completed in the past 6 mo. These include a calculation of the kinetic equation for an inhomogeneous plasma in a uniform external magnetic (Ref. 4) field. It is assumed in this work that the system is not far from equilibrium. In another important application, Wu extended previous work on the high frequency conductivity of a plasma in quasi-equilibrium (Ref. 3) to include the effect of an external magnetic field (Ref. 5).

Also completed in this period was the work on the collision-induced high frequency instability for a plasma with a relative electron/ion drift (Ref. 6). This work indicates that, if the relative drift exceeds 1.37 times the electron thermal speed and if the ion/electron temperature ratio exceeds 1.07, the collisional mechanism will cause the system to become unstable.

Work is in process on the study of the limits of validity of conventional approximations leading to the existence of ion waves in a two-temperature plasma ($T_e \gg T_i$). This work will be extended to include a study of the plasma with a drift and possibly to include a magnetic field.

Experimental work under this task is included with reports from the Fluid Physics Section, 327. In FY 1966, the Plasma Theoretical Program will all be carried on under the Work Unit titled "Theoretical Physics Research."

B. AN EXPERIMENTAL STUDY OF A NEUTRAL POINT IN A PLASMA*

It is well known that neutral points and lines play an essential roll in hydromagnetics on the astrophysical scale. While the subject has received considerable theoretical attention (for example, theories of solar flares) (Ref. 7), we believe this is the first experimental study conducted for this specific purpose. The experiment consists of two inverse pinch devices mounted side by side in a common vacuum chamber (Fig. 1). We observe the collision of two magnetically-driven cylindrical shocks. Properties of the inverse pinch have been studied by others (Refs. 8, 9) and seem reasonably well understood. The shocks produced follow the simple snow plow model reasonably well and are shown in Fig. 2.

---
*A. Bratenahl and W. Hirsch

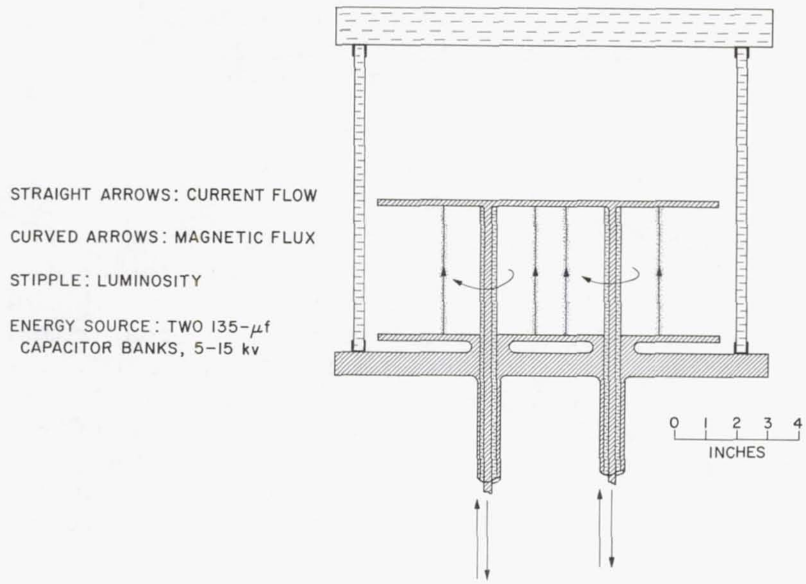


Fig. 1. Double inverse pinch

Straight arrows show current flow, straight arrows show magnetic flux (Energy source = two 135 μf capacitor banks, 5 to 65 kilovolts)

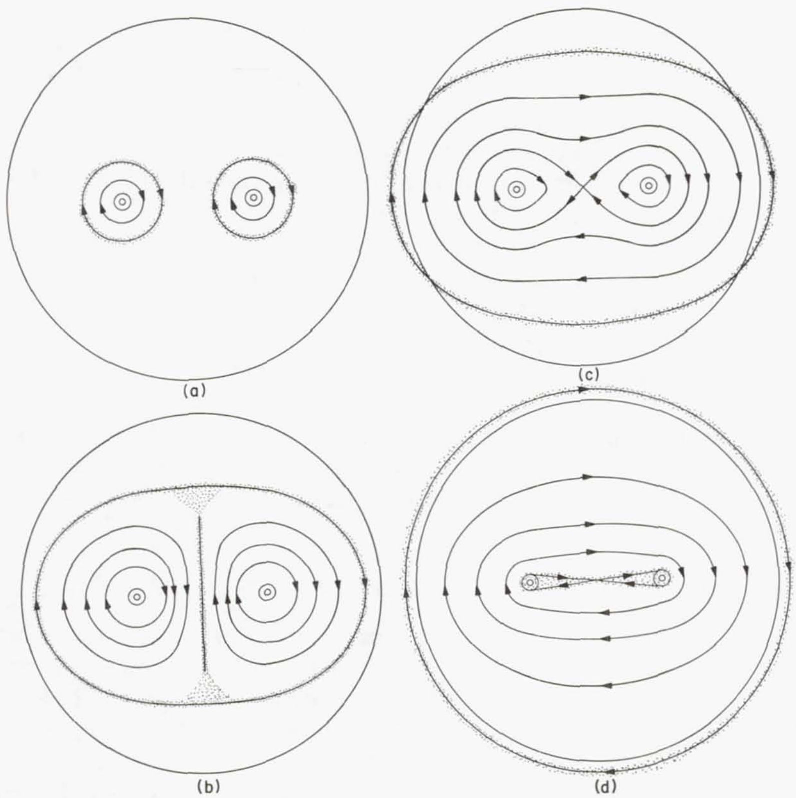


Fig. 2. Stipple luminousity

a) Before collision
b) After collision
c) Current maximum
d) First current zero

It should be made clear, however, that even when the gas is well ionized ahead of the shock, the magnetic piston is leaky, and highly conducting plasma exists in the region behind the piston. It is precisely the region behind the piston that is of interest in this experiment, and we can estimate from its behavior that the magnetic Reynolds number is of the order of 50. This is large enough to permit making some analogies on the astrophysical scale.

The degree of overall reproducibility from shock to shock came as an agreeable surprise. With a Kerr-cell camera of 0.2 μsec open-time, one can produce single frames of the shock propagation and collision that may be fitted together to form a rather convincing kinematic presentation. One-half period of the driving current is 20 μsec. The fronts collide at 4 μsec, moving at a velocity of 1.2 cm/μsec. The interface between the expanding cylinders flattens into a brilliant sheet during the first 4 μsec, suggesting the formation of a sheet pinch with storage of magnetic energy which is then followed by a thinning and darkening in the central portion, suggesting the formation of a neutral point and flux relinking. Later, the two flattened cylinders merge into a single expanding oval about 13 μsec, just past current maximum.

Just before the second half-cycle propagates a second pair of shocks, a bright line of light suggesting a pinch is seen connecting the two current rods. This bright line is at right angles to the original collision layer. It could easily be established that we were observing a sheet pinch in the residual gas left behind the initial shock, produced when the voltage across the device reverses sign (current maximum). The magnetic flux surfaces normally would reenter the glass insulator surrounding the conducting rods, but here the coupling of the residual plasma to this flux produces an inward flow that stagnates against the insulators. Over the insulators, then, a current flows (in effect short-circuiting the device internally), trapping the flux introduced during the first quarter-cycle. The magnetic pressure of this flux decays faster on the inside of the asymptotic lines of the neutral point than on the outside because the resistence of the current path against the insulator is larger than that against the vacuum wall in the ratio of the circumference of these current sheets. The 90 deg neutral point is flattened into a sheet pinch. The shocks produced in the second half-cycle run into this sheet pinch from each end, and all these observations are a demonstration of the existence of the high magnetic Reynolds number plasma in the region behind the first shocks. An estimate can be made of the density of this region from the velocity of the snow plow of these second shocks. The bulk of the gas swept out by the first shock is held in the vicinity of the outer wall by the trapped flux, but by the time the second shocks have run half-way out, the trapped flux has decayed enough to permit infalling of this gas where it meets the outgoing pair of shocks. The interaction is quite visible.

With this background of pictorial data, a double magnetic probe was introduced. The probe is a 3 mm OD quartz tube closed at the end, inside of which are mounted two 10-turn coils, one inside the other, with their axes at right angles. By integrating the voltages induced in these coils, the component fields B_x and B_y can be determined at a given point as a function of time. The component fields are plotted on a polar diagram from which the magnitude and direction of the local field can be plotted as a function of time.

The results came as a considerable surprise. Aside from providing complete support for the hypothesis concerning the trapped flux and the formation of the second sheet pinch at right angles to the first, etc., toward the end of the first half-cycle, the time dependence of the field angle clearly demonstrates that the flux relinking takes place intermittently (with a period of approximately 2 μsec) during the first quarter-cycle. The exact phase and magnitude of each event varied from shock to shock characteristic of the operation of instabilities. It is clear from the magnetic probe data (Fig. 3), that we are dealing with two distinct magnetic configurations, Fig. 4: (1) a sheet pinch or collision layer of large current density separating antiparallel fields; (2) an x-type neutral line with considerably reduced current density across which magnetic flux is being rapidly relinked.

According to Furth, Killeen, and Rosenbluth (Ref. 10), the sheet pinch is unstable (finite resistive tearing mode) to the formation of a neutral point. The relinking of flux at the neutral point can proceed much faster than by simple resistive diffusion through the cooperation of a pair of switch-off shock waves, according to Petschek (Ref. 11). On the other hand, according to Dungey (Ref. 12) and Chapman and Kendall (Ref. 13), an x-type neutral point is hydromagnetically unstable (even in the infinite conductivity limit) to the formation of a sheet pinch. Thus, the two

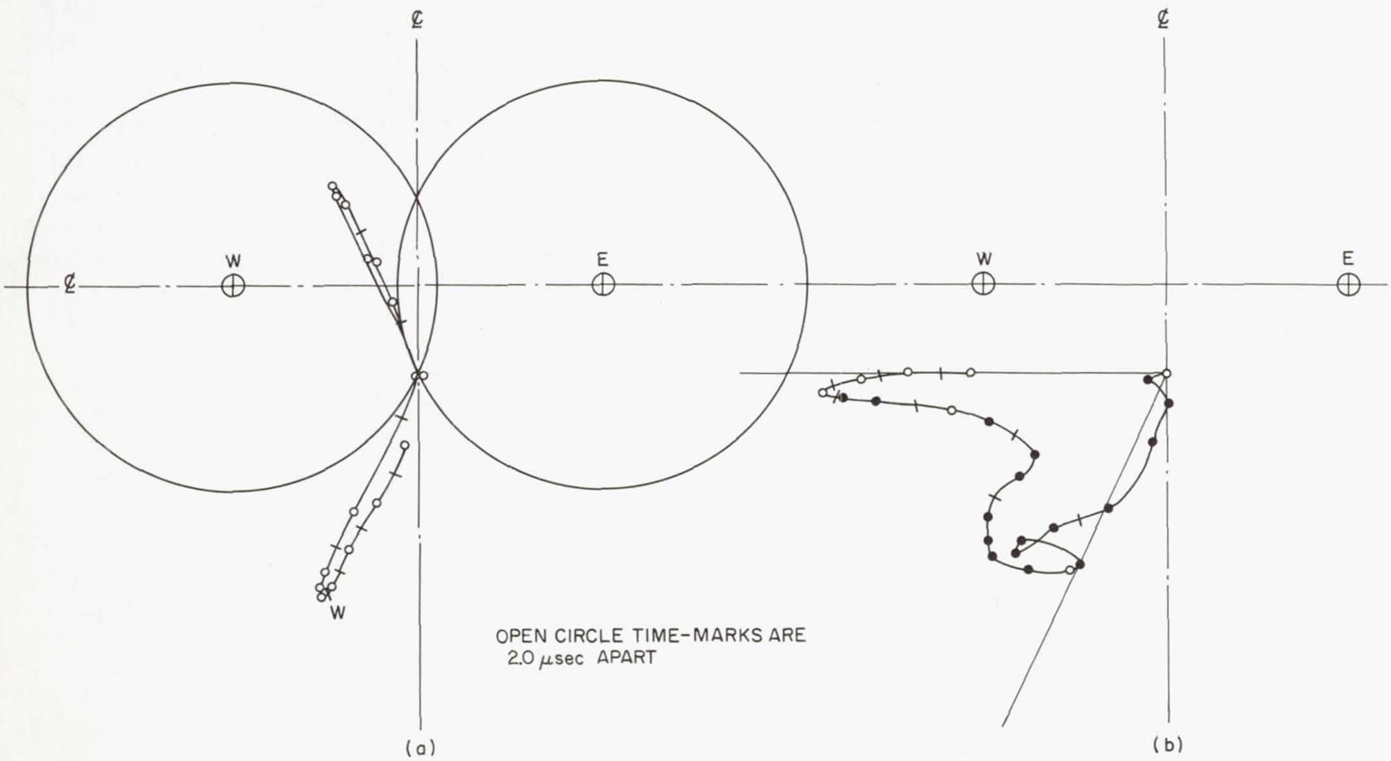


Fig. 3. Magnetic probe data (open circle time-marks are 2.5 μsec apart)
a) Polar plot of "east" and "west" bank separately
b) Behavior at point slightly "west" of electrical midplane after collision of two shocks

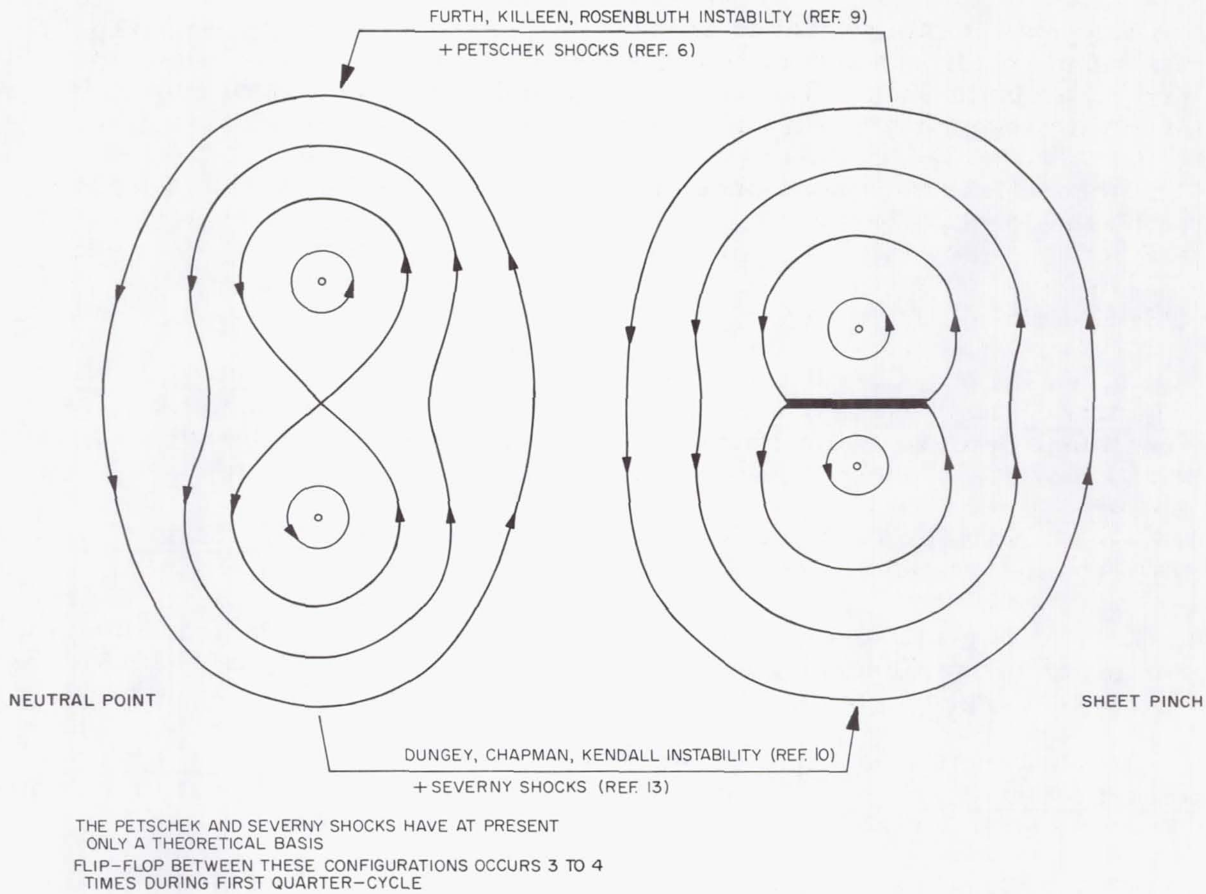


Fig. 4. Two magnetic configurations, each unstable to formation of the other. The shocks, Petschek (Ref. 11), Severny (Ref. 15), now have only a theoretical basis. Flip-flop between these configurations occur three to four times during the first quarter-cycle. Figure adopted from P. A. Sweet (Ref. 16).

observed states are each unstable to the formation of the other. During the time energy is flowing into the system (first quarter-cycle), we observe a flip-flop between these states.

This somewhat unexpected behavior of a neutral point in a plasma is, of course, only a particular resolution of an interesting configurational conflict (a steady-state solution may be possible). It is interesting to speculate if the ambiguous and conflicting observed magnetic behavior of flares might be due to a flip-flop process such as this. Repeating, that is, so-called homologous flares following "some blueprint that is characteristic of the site" that "does not seem to be destroyed by the individual flares," Parker (Ref. 14), might also find an explanation in such a flip-flop process.

To establish the details of what is occurring will require the measurement of the vector fields at two points simultaneously, so that the local curl of B may be determined. Of greater significance at this stage in the investigation will be a search for runaway electrons and X-rays from the pinch and accelerated plasma jets from the fast relinking process, correlating these events with the magnetic behavior.

One might also expect rapid changes in spectral line widths because of Stark and doppler broadening. It is hoped to obtain a fast-framing camera to study the detailed morphology in a single shock (Kerr-cell photography of single frames provided very little hint of the fast changes actually taking place).

The theoretical work done under this task has been included in a review presented by the Physics Section.

C. REFERENCES

1. Klevans, E. H., Wu, C.-S., and Primack, J. R., High Frequency Conductivity Calculation Using the Plasma Kinetic Equation, to be presented at the 7th International Conference on Phenomena in Ionized Gases, Belgrade, Yugoslavia, August 1965.

2. Wu, C.- S, "A Useful Operator in Plasma Kinetic Theory," J. Math. Phys., Vol. 5 1701 (1964).

3. Wu, C.- S., "High Frequency Conductivity of a Plasma in Quasiequilibrium. I. Formulation of the General Theory," Phys. Rev., Vol. 138, A51 (1965). See also, Space Programs Summary 37-31, Vol. IV, Feb. 1965.

4. Wu, C.-S., Kinetic Equation for an Inhomogeneous Plasma in a Uniform External Magnetic Field. To be presented at the 7th International Conference on Phenomena in Ionized Gases, Belgrade, Yugoslavia, August 1965.

5. Wu, C.-S., "High Frequency Conductivity of a Plasma in Quasiequilibrium. II. Effect of a Uniform Magnetic Field," submitted to Phys. Rev., March 1965.

6. Klevans, E. H., Wu, C.-S., and Primack, J. R., Collision-Induced High-Frequency Instability for a Plasma with a Relative Electron-Ion Drift. To be presented at 7th International Conference on Phenomena in Ionized Gases, Belgrade, Yugoslavia, August 1965.

7. Various authors, Physics of Solar Flares, NASA SP 50, 1963.

8. Vlases, George C., Phys. Rev. Let., Vol. 12, 43, 1964.

9. Johansson, Rolf B., Phys. Fluids, Vol. 8, 866, 1965.

10. Furth, H. P., Killeen, J., and Rosenbluth, M. N., Phys. Fluids, Vol. 6, 459, 1963.

11. Petschek, H. E., Physics of Solar Flares, NASA SP 50, 1963, p. 425.

12. Dungey, J. W., Cosmic Electrodynamics (Cambridge Univ. Press 1958).

13. Chapman, S., and Kendall, P. C., Proc. Roy. Soc., 271, 435, 1963.

14. Parker, E. N., Ap. J. Supplement No. 77, 8: 177, 1963.

15. Severny, A. B., Astron. J. SSSR 37, 609, 1960.

16. Sweet, P. A., Physics of Solar Flares, NASA SP 50, 1963 p. 409.

Page Intentionally Left Blank

QUANTUM CHEMISTRY
NASA Work Unit 129-02-03-04
JPL 329-20801-1-3260

The ab-initio BE atom calculation via the Sinanoglu many-electron-theory has been completed. Six configurations have been used in linear combination with the Hartree-Fock BE functions of Roothaan, Sachs, and Weiss and the results minimized to obtain the best correlation energy. The calculated $(1s)^2$ correlation energy plus the calculated $(2s)^2$ correlation energy when combined with a perturbation 1s-2s intershell correlation calculation by Kelly give 98% of the total correlation energy. A paper covering the Be atom results and discussion about the ease, practicality, and utility of the many-electron theory has been submitted and accepted for publication in the Journal of Chemical Physics and is scheduled to appear September 1. Work is now in progress to extend the calculation to the four-electron series isoelectronic with Be, viz., B^+, C^{++}, ...

The general area of evaluation of integrals needed in quantum chemistry is under continuing scrutiny. The Fourier convolution theory, extended by this group, is being applied to three-electron integrals and to many-center integrals. Other techniques, like those recently developed by Schrader (*J. Chem. Phys.*, 41, 3266, 1964), Bonham, Peacher, and Cox (*J. Chem. Phys.*, 40, 3083, 1964), and by Harris and Michels (*J. Chem. Phys.*, 42, 3325, 1965), are being analyzed. Attempts are being made to evaluate zero-field splitting exchange integrals analytically and in closed form.

A theory for calculating the energies of negative ion resonant elastic scattering states, where the usual variation principle is not applicable, has been proposed and applied to the H_2^- resonances observed by Simpson, et al., and the H^- resonances observed by Schulz. The theory is based on a quasi-variation principle and is shown to give excellent results in those cases considered so far. A paper submitted to the Journal of Chemical Physics has been accepted and is in press. More work will be done in this area during the next fiscal year.

Other main areas of continuing and new interest are:

1. Analysis of small diatomic molecules by the method of configuration interaction based on the use of elliptical orbitals as developed by Harris and Taylor. The delay in this area is based on the lack of manpower and computer time exclusively as the computer programs are running.

2. Studies of the electronic properties of triatomic molecules. This involves solving the Hartree-Fock equations self-consistently, evaluation of the three-center integrals by the Barnett-Coulson method, and combining of the two programs to make them compatible. Studies on the H_2O, H_3, and CH_2 will soon be completed.

3. Infinite configuration interaction method is being applied to the Helium atom. This is based on Kelly's findings that the virtual states obtained in Hartree-Fock calculations are all continuum states, thereby reducing the infinite secular equation to a finite

number of integral equations. The analysis has been completed, but the numerical programming difficulties have been almost insurmountable so far.

4. Detailed investigation of upper and lower bounds, perturbation theory, and convergence properties of trial wave functions to be able to assess the "goodness" of approximate wave functions.

5. Smaller problems as computation of the momentum space wave function by iterative technique of solving the integral equations resulting for Helium, analysis of two-electron correlation functions by the Pluvinage method, etc.

Within the past 6 mo, the members of the Quantum Chemistry group at JPL, Murray Geller, and consultants Howard Taylor and Donald Merrifield, have given lectures at Cal Tech, La Jolla, UCLA, Stockton, and Columbia, among others.

RADIATION CHEMISTRY
NASA Work Unit 129-02-03-06
JPL 329-21301-1-3260

The theoretical treatment of gas-solid interactions, arising from the investigation of the radiation chemistry of the hydrogen isotopes, has been completed and accepted for publication by the Journal of Chemical Physics. The treatment deals specifically with the low temperature chromatographic separation of the hydrogen isotopes on an alumina column. All the observed phenomena are explained by a simple electrostatic theory of the nature of the electric fields at the surface of ionic crystallites. One observation, which had never previously been explained, is that the ortho- and para-species of hydrogen and deuterium are separable on an alumina column at low temperatures. For these species to be separated some type of hindered rotation must exist on the alumina surface. The theory treats this hindered rotation and shows that the barrier to rotation arises from the difference in $\alpha \parallel$ and $\alpha \perp$, the parallel and perpendicular components of the molecular polarizabilities of the isotopes because the gases are attracted to the surface by electric field-induced dipole interactions.

The electric field intensity on the {100} plane of an Al_2O_3 surface determined by summing, with the aid of a 7094 IBM Computer, the contribution of each ion of the crystal. There are two active adsorption sites at 77.4°K, one over a vacancy in the Al_2O_3 structure and the other over an Al^{+3}. The total interaction potential over both sites was determined as a function of the polarizabilities of the adsorbed molecules and the distance the molecules are from the surface.

A 5-9 potential over a vacancy site gives results that favorably agree with experimental values of the chromatographic separation of the isotopes at 77.4°K.

Some of the predictions made by the theory have since been verified in the laboratory. The separation factors of the rare gases on an alumina chromatograph column at room temperature have been found to be a logarithmic function of their respective polarizabilities as suggested by the theory. A manuscript based on the work is now being prepared for external publication.

The theory has applications in fields other than chromatography. For example, the principles of the theory have been applied to explain the mechanism of general anesthesia in the brain and also to show that gaseous adsorption on so-called molecular sieves is not a sieve action, but is based on electrostatic interactions between the gases and the electric fields that are present in the molecular sieves. A manuscript describing this work is also in preparation.

The theory finds additional applications in the investigation of the radiation damage in solids. It proposes a sensitive measure of the effect of radiation damage on surfaces by the use of ortho- and parahydrogen as probes. Finally, the theory can be applied to other new fields, such as the surface states of metals and the charge density at the surface of metals. Future investigations will involve the application of the theory to these new fields.

The investigation of the reaction of atomic oxygen and hydroxyl radicals at trace concentrations in an environment of nitrogen gas has been completed and the manuscript is being prepared for publication.

PUBLICATIONS DURING THE PERIOD

1. King, James, Jr., and Benson, Sidney W., Theory of the Low Temperature Chromatograph Separation of the Hydrogen Isotopes, JPL Space Programs Summary 37-33, Vol. IV.

2. King, James, Jr., and Benson, Sidney W., "A Theory of Adsorption of Gases on Solids" (accepted for publication by the Journal of Chemical Physics).

3. King, James, Jr., Polarization Effects in the Chromatographic Separation of the Rare Gases on an Alumina Column, JPL Space Programs Summary 37-33, Vol. IV.

4. King, James, Jr., Photolysis of Low Concentration of Nitrogen Dioxide at 3660A, JPL Space Programs Summary 37-33, Vol. IV.

NUCLEAR PHYSICS RESEARCH
NASA Work Unit 129-02-03-08
JPL 329-21701-1-3280

Conditioning of the Dynamitron positive ion accelerator has been under way since November 1964. Conditioning of the beam tube, with positive ion beam, was thought to be nearly complete in April and May when large beams of protons and deuterons were produced at high energies. However, electrical breakdown inside the beam tube damaged the ion source and some of the dynodes. It became necessary to replace the beam tube and repair the ion source. The new beam tube, which arrived in mid-June, is now undergoing conditioning. The accelerator performance falls short of specifications and negotiations are underway concerning acceptance at reduced specifications.

The permanent Dynamitron facility in Building 183 is nearing completion. The accelerator and the experimental equipment are to be moved in the fall.

A contract for a multiparameter data-acquisition system was awarded to Nuclear Data, Inc., in June. Delivery is expected about mid-August. Procurement of a beam-analyzing magnet is in the precontract stage.

Experimental equipment for the evaluation of neutron fluxes produced by the Dynamitron has been designed, constructed, and tested. As soon as the accelerator is able to produce positive ion beams routinely, measurements of angular and energy distributions will be made for the H^3 (d, n) He^4, H^3 (p, n) He^3, H^2 (d, n) He^3, and B^{11} (d, n) C^{12} reactions. Preliminary results from an experiment designed to provide integral energy spectra of electrons emitted when fission fragments pass through thin foils will soon be available. Other experiments for which equipment is being constructed or tested are concerned with spontaneous fission of metastable AM^{242m}, specific energy loss of fission fragments in matter, and differential energy spectra of secondary electrons.

Theoretical calculations on the ultimate energy resolution of semiconductor detectors used for fission fragments are complete. Preliminary results were accepted for publication as a letter titled "Resolution of Semiconductor Detectors for Fission Fragments," by the Review of Scientific Instruments. Final results may be presented at the 12th Nuclear Science Symposium, IEEE, October 18-20, 1965 in San Francisco. The abstracts for this and other work were submitted for presentation at the above-mentioned symposium under the titles:

Pulse-Height Defect and Energy Resolution in Semiconductor Detectors, Eldon L. Haines and A. Bruce Whitehead.

Yield and Energy Spectrum of Secondary Electrons Generated by Fission Fragments, A. Bruce Whitehead.

Neutron Production Using a Dynamitron Accelerator, Richard H. Parker, Eldon L. Haines, Walter F. Wegst, and A. Bruce Whitehead.

Page Intentionally Left Blank

OPTICAL PHYSICS RESEARCH
NASA Work Unit 129-02-05-01
JPL 329-20101-1-3450

ELECTRO-OPTIC EFFECT

The investigation of the electro-optic effect in single crystal $BaTiO_3$ during the last 6 mo has been concentrated on measurements under the condition of constant strain. The low frequency results are complete, and have been reported in the Journal of the Optical Society of America (Ref. 1). The method for making the strain-free measurements through observation of the transient response of a single-crystal sample to an applied field in the form of a step function is now developed to a point of reasonable convenience and accuracy. The applicable response time of our fastest photomultipliers is approximately 5 nanoseconds, while all other components of the apparatus are capable of one order of magnitude faster responses. The 5-nanosecond response is fast enough to satisfy the strain-free requirements, but remains as the single predominant factor limiting overall response time.

The measurement has now been made on three crystal samples for each configuration, thus avoiding error from domain structure and sample-to-sample variation. An [001] field is used to measure $r'_{33} - r'_{13}$, and a [100] field, for measuring r'_{42}. The primes are used to designate values of the electro-optic coefficients under the strain-free condition. Here, r_{ij} is defined by

$$\Delta(1/n_i)^2 = \sum_{j=i}^{3} r_{ij} E_j ,$$

where

n   is the index of refraction

E   is the applied field, and the conventional contracted subscripts are used.

Strain-free dielectric constants were measured on crystals from the same lot by a similar transient method. Empirically, the optical response per unit induced polarization, $r/(\epsilon - \epsilon_o)$, is a useful quantity, being nearly constant with temperature, and even of similar magnitude (within about a factor of two) for different materials (Ref. 2). Here, ϵ is the appropriate dielectric constant for the configuration used, and ϵ_o is the dielectric constant of a vacuum. Our results show that $BaTiO_3$ fits this concept fairly well, except that for a low-frequency [001] field, the quantity $(r_{33} - r_{13})/(\epsilon_c - \epsilon_o)$ decreases with rising temperature, and is significantly smaller under strain-free conditions.

Analogous measurements of the quadratic (Kerr) effect above the Curie transition at 120°C were made, with the unexpected result that there is a large (60%) strain contribution even in the cubic state. There can be no piezoelectric strain in cubic $BaTiO_3$, so our present interpretation is that the electrostrictive strain (proportional to E^2) is responsible for the observed clamping effect. Previous discussions in the

literature, for example, have assumed that no clamping is possible in a centrosymmetric crystal structure (Ref. 3).

A paper describing these results has been prepared and has been submitted to Applied Physics Letters. A more general paper on the applications of the electro-optic effect, and the influence of the strain-optical coupling has been accepted for presentation at the AGARD symposium on Opto-Electronic Components and Devices, in Paris, in September 1965. Also, a detailed paper on the technique of measuring rapidly changing birefringence is planned for the Journal of Applied Optics.

Further work will include interpretation of the experimental results for $BaTiO_3$ to provide a useful model to explain them.

Also, it is important to extend the same kind of measurement to other crystals, and efforts will be made to obtain a variety of suitable crystal samples.

References

1. Johnston, A. R., and Weingart, J. M., J. Opt. Soc. Am., Vol. 55, XXX (1965) (July issue).

2. Miller, Robert C., Appl. Phys. Lett., Vol. 5, 17 (1964).

3. Geusic, J. E., Kurtz, S. K., Van Uitert, L. G., and Wemple, S. L., Appl. Phys, Lett., Vol. 4, 141 (1964).

OPTICAL SECOND ORDER POLARIZATION COEFFICIENTS

The experimental phase of the determination of the optical second order polarization coefficients of barium titanate is essentially complete.

Ample data to determine the three coefficients, d_{13}, d_{33}, and d_{42} as a function of temperature has been recorded, and all that remains is to perform a calibration check of the phototubes used.

Because the measurement was performed in reflection from a surface at an angle of incidence different from zero, there is some possibility that the surface itself will contribute some second harmonic independent of that which is generated on the surface layer of the crystal. Because of lack of time, however, it was not possible to investigate this experimentally. Indications are that the surface contribution is probably small.

Future work will include completion of the data reduction on the recently completed temperature runs, interpretation of results, and preparation of a final report. A paper will also be presented at the fall meeting of the American Optical Society.

Present plans are to select a new project and to initiate work on it during the next 6-mo period.

STRUCTURE AND PHOTO-CONDUCTIVE PROPERTIES OF EVAPORATED CADMIUM SULFIDE FILMS

This work was started on April 30, 1965, on which date the principal scientist arrived from Japan as a resident research appointee at JPL. A brief description of the present investigation is as follows:

1. General

Cadmium sulfide thin films evaporated in a vacuum may be used as photoconductive sensors and as dielectrics in electronic devices. The object of this research is to study the relationship between the structure and photoconductive properties of these thin films. The following will be checked as functions of the evaporation rate, the temperature of the source and the substrate, sticking probability of the vapor molecules to the substrate, and also the surface condition and material of the substrate:

1. The composition of the cadmium sulfide vapor in its molecular beam.
2. The crystal, textural, and defect structures of the cadmium sulfide films.
3. The effects of impurities.
4. Photoconductivity.

2. Experimental procedures

a. Vapor analysis. The composition of cadmium sulfide vapor evaporated from a source will be analyzed by using a mass-spectrometer.

b. Structure analysis. The structure of the film will be checked by X-ray and electron diffraction methods, the surface state by electron-microscopy, and the composition by fluorescent X-ray analysis.

c. Measurements on resistivity and photoconductivity. The resistivity, Hall coefficient, and mobility of electrons will be measured as a function of light intensity by using ohmic contact electrodes.

3. Test apparatus.

The following test apparatus will be used:

1. Vacuum unit (VEECO, VE-400).
2. Quadrupole residual gas analyzer (Varian, Model 980-120).

3. Quartz crystal balance (Westinghouse, Model 701).

4. Quartz crucible or oven to produce the molecular beam of cadmium sulfide.

PUBLICATIONS

1. Johnston, A. R., and Weingart, J. M., "Determination of the Low-Frequency Linear Electro-Optic Effect in Tetragonal $BaTiO_3$," J. Opt. Soc. Am., Vol. 55, XXX (July 1965).

2. Johnston, A. R., "Linear Electro-Optic Effect in Tetragonal $BaTiO_3$," Bull. Am. Phys. Soc., Vol. 10, 473 (1965).

3. Johnston, A. R., Electro-Optic Crystals and Their Use for Light Modulation, to be presented at the Ninth Technical Meeting of the AGARD Avionics Panel, September 6-9, 1965, Paris, France.

4. Johnston, A. R., "The Strain-Free Electro-Optic Effect in Single-Crystal Barium Titanate," submitted to Applied Physics Letters.

5. Shumate, M. S., Theory of Optical Harmonic Generation in Barium Titanate, p. 93, JPL Space Programs Summary 37-31, Vol. IV.

6. Shumate, M. S., "Interferometric Measurement of Large Indices of Refraction," submitted to the Journal of Applied Optics.

CRYOGENICS RESEARCH
NASA Work Unit 129-02-05-02
JPL 329-20201-1-3450

CRYOGENIC GYRO

At the start of the current 6 mo reporting period, the cryogenic gyro had been brought to the stage of development so that meaningful drift data could be obtained. The primary objective during this period has been to develop techniques to evaluate the drift of the cryogenic gyro and to correlate the drift with known sources of torque.

The problem of readout has been studied. Of the various systems conceived that fulfill the requirements of an all attitude readout not involving a preferred rotor axis, the following was adapted. In this system two microscopes equipped with dark field illuminators and angular readout reticle eyepieces are used. These are mounted with their axis perpendicular to the surface of the rotor and at right angles to each other. The direction of rotary surface motion will be detected visually and aligned with the reticle eyepiece, and the angle read out on a graduated circle. The direction of the spin axis is computed as the vector cross product of the vectors describing the surface motion in the two viewing planes. An anodized grid of dots will be applied to the rotor to aid in discerning the surface motion; however, this does not place any requirements on placement of the pattern relative to the spin axis (which would be inacceptable inasmuch as the pole wanders on the rotor surface).

To separate the effect on drift of trapped flux and London moment from the effect of nonsphericity, an analysis has been made of support field configurations to determine whether reversal of the field can be achieved without losing levitation. Several solutions to this problem have been demonstrated but none are altogether desirable. A choice must be made between techniques for slow deformation of the field configuration vs rapid reversal of the field polarity with no intermediate change in configuration. To study this problem, the restoring forces on a diamagnetic sphere in a magnetic field have been calculated for the most general case. The solution will appear in a forthcoming Space Programs Summary.

In addition, a solution to the calculations of torques on a superconducting sphere containing arbitrary trapped flux has been obtained and will appear in Space Programs Summary No. 37-33 Vol. IV. This complements the calculations of torque on an imperfect sphere (Space Programs Summary 37-24 Vol. IV p. 35), which were confirmed experimentally for an ellipsoid as described in Space Programs Summary 37-31 Vol. IV p. 92.

Additional drift data has been obtained using twice-per-day polar readout for rotors spinning perpendicular to Earth's polar axis. Drift data varied between 4 and 20 deg/day. In one experiment, the rotor was spun nearly about the Earth's polar axis and the rotor pole was observed continually over a 31-hr period. The result was an expected ellipse with a closure error of about 1 hr.

During the next 6 mo period, the techniques described above will be developed further and used to quantitatively determine the torque because of nonsphericity, the torque because of trapped flux, the torque because of the London moment, and any residual torque that may remain after these sources of torque have been accounted for

VELOCITY AND ATTENUATION OF SOUND IN LIQUID HELIUM

This work is concerned with sound propagation in liquid helium below 1°K over a wide range of frequencies. During the past 6 mo we have completed the construction of a cryostat in which temperatures extending to 0.3°K will be reached and maintained. The design is based on that of similar devices described in the literature. The gas ^{3}He, which is contained and circulated within a closed system, is condensed at a temperature of approximately 1.3°K into a reservoir in contact with the bath of liquid ^{4}He in which the ultrasonic apparatus is immersed. Lower temperatures are achieved by evacuating the space surrounding the ^{3}He reservoir and the inner bath, to isolate them thermally from the outer ^{4}He bath, and then pumping on the ^{3}He.

Tests of the system have been made during the past 3 mo. The design of the ^{3}He circulation system and all the auxiliary apparatus has proved to be very satisfactory, but the part of the cryostat in which the ^{3}He reservoir is placed will require modification. The heat leak into the inner bath is much higher than was anticipated: 5 to 10 mw, as compared with what had been regarded as a conservatively-estimated upper limit of 1 mw; and the lowest temperature reached to date is 0.5°K. During the past few weeks we have been trying to find the unknown heat source. Our present conclusion is that heat is carried from the outer bath to the ^{3}He reservoir by sustained oscillations, somewhat like those that occur in a Helmholtz resonator, in the tube connecting the reservoir to the outer bath. In one experiment, in which we were able to inhibit the oscillations, the heat leak into the reservoir was 0.03 mw, well within our original estimate. Unfortunately, we could not measure the ultimate temperature reached during this run, but we estimate that it was in the neighborhood of 0.3 to 0.4°K. The ^{3}He reservoir is now being dismantled so that appropriate changes can be made.

A paper titled "Temperature and Frequency Dependence of Ultrasonic Absorption in Liquid Helium below 1°K," by W. A. Jeffers, Jr. and M. W. Whitney, was submitted to the Physical Review in March and is scheduled to appear in the August 14, 1965 issue. Analysis made in the preparation of this paper shows that it is the high-frequency behavior of the velocity and attenuation that is now of main interest, and the original plans to make measurements at frequencies below 1 Mc have accordingly been changed. The experiments will be made initially at 10 Mc, and will be extended, if possible, to frequencies well above 100 Mc.

A paper titled "Velocity of Sound in Liquid Helium II" is being written in collaboration with C. E. Chase of the National Magnet Laboratory, M.I.T., and will be submitted to the Physical Review during the next 6-mo period.

PUBLICATIONS

1. Whitney, W. M., Identification of a Mechanism for Sound Absorption in Liquid Helium Below 1°K, p. 64, JPL Space Programs Summary 37-30, Vol. IV.

2. Harding, J. T., Analysis of Torques Exerted on a Spherical Superconductor Due to Trapped Flux in an Axially Symmetric Magnetic Field, JPL Space Programs Summary 37-33, Vol. IV., to be published.

3. Harding, J. T., "Drift Data for the Cryogenic Gyro," International Advances in Cryogenic Engineering (Plenum Press, New York, 1965), Vol. X, p. 137.

Page Intentionally Left Blank

LOW TEMPERATURE PHYSICS
NASA Work Unit 129-02-05-04
JPL 329-20401-1-3280

SUPERCONDUCTIVITY STUDIES

Hollow superconducting tubes have been studied in zero magnetic field in a shielded enclosure. The experiments revealed that thick-walled lead tubes exhibit a nonzero trapped field in zero applied field. These spontaneous fields are believed to be due to thermoelectric currents induced at the time of transition, because they can be affected by temperature gradients. These affects are absent in niobium foils and in accurately evaporated lead films. A Mercereau bridge magnetometer has been constructed to study the details of the fields. The understanding of these fields is necessary before any absolute zero field region can be developed.

The shielded enclosure for these experiments is a "mu-house" that is removed from the main part of the Laboratory. The remote nature of the facility and its required use for testing flight apparatus have proved limitations in superconductivity studies. It is hoped that these difficulties will be overcome with a "mu-box" to be constructed in the new Space Sciences Research Building. The material is on order and the device will be fabricated in the next quarter.

Macroscopic quantization experiments in liquid helium have been planned and will be started in the next fiscal year.

The future program has been discussed with Paul Johnson of the OART Electrophysics Branch. A publication under this subject is A. F. Hildebrandt's, The Superconducting Transition of a Hollow Rotating Cylinder in a Magnetic Field, JPL Space Programs Summary 37-32.

NUCLEAR MAGNETIC RESONANCE STUDIES

The major emphasis of the nuclear magnetic resonance (NMR) program has been the development and application of multiple-irradiation techniques in the analysis of high resolution NMR spectra. The data obtained from the analysis of the NMR spectra gives new information on the molecular electronic structure of the molecules studied. In addition, experiments have been conducted to study the feasibility of nuclear magnetic resonance techniques for various space science experiments.

Activities During Report Period

Contributions to Space Programs Summary, Presentations, and Publications

1. "Relative Signs of the Nuclear Spin Coupling Constant in Propylene Oxide and Indene Oxide," J. Chem. Phys., Vol. 42, 650 (1965).

2. "The Relative Signs of the NMR Proton Coupling Constants in Styrene Sulfide and Styrene Irmine," J. of Am. Chem. Soc., Vol. 87, 220 (1965).

3. "Analysis of the NMR Spectra of the Vinyl Protons of Cyclopentadiene and Tyclohexadiene Using Spin Decoupling," submitted for presentation at September National American Chemical Society meeting at Atlantic City.

4. "Internal Field Lock Systems," Invited talk presented at 6th Conference on Experimental Aspects of NMR. Mellon Institute, Pittsburgh, Penna., Feb. 28, 1965.

5. On the Correlation of Geminal and Vicinal Nuclear Magnetic Resonance Spin Coupling Constants with Substituent Electronegativities, JPL Space Programs Summary 37-33, Vol. IV.

Instrumentation

1. Constructed and tested a method for using an external sample for frequency-field locking the NMR spectrometer. With this method, the first field-lock spectra were obtained of N^{14}, C^{13}, B^{11}, and P^{31}. Patent possibilities for this method are being explored in view of its great potential value for a variety of applications.

2. Constructed and used a new linear sweep system for the HR 60 field-lock NMR spectrometer. A frequency-to-voltage conversion unit is used with an X-Y recorder to give a sweep linearity improvement of several orders of magnitude. Additional spectral stability was obtained with the use of this system.

3. Purchased a Varian time-average integrator unit, which is being tested with the A-60 NMR system. In addition, circuitry is being designed so that the time-average integrator can be used for N^{14}, C^{13}, B^{11}, and P^{31} studies with the HR 60 spectrometer field lock system.

4. Overhauled A-60 NMR spectrometer receiver and recorder circuits.

5. Constructed a new phase detector and used it in the feasibility study for a wide-line NMR spectrometer, possibly appropriate for a Mars Voyager experiment or a Lunar soft-landing experiment. These studies indicated that NMR techniques could be used to analyze for water in lunar and Martian soil and rock samples; they could also provide data on the seasonal variation of moisture in the Martian soil and atmosphere.

Meetings Attended. Attended the "Sixth Conference on Experimental Aspects of NMR" at Mellon Institute, Pittsburgh, Penna., Feb. 28, 1965. Presented an invited paper at the meeting and, in addition, was chairman of a session on "Superconducting Solenoids."

Future Activities Planned

1. Preparation for publication of several manuscripts on high resolution nuclear magnetic resonance experiments for which data have already been obtained.

2. Continuation of experiments on multiple-irradiation nuclear magnetic resonance studies.

3. Continuation of work on the study of NMR techniques in the analysis of water content of lunar and planetary samples. Study of the possibility of flight type instruments for soft landing experiments. Extension of the NMR technique to the study of other nuclei in the flight studies.

DE HAAS-VAN ALPHEN EFFECT STUDIES

The objective is to advance the state of knowledge of the electronic band structure of the metals that are of technological importance as superconductors. The research is expected to lead to a better understanding of superconducting properties. Niobium is the main constituent of the important superconducting alloys, but its electronic band structure is unknown; hence, it will be studied first.

The primary reason the hand structure of niobium is unknown is because the high purity samples required for studying the properties are not available. To overcome this problem, a new method has been devised for analyzing de Haas-van Alphen data, which effectively increases the sensitivity of the experimental technique. The method consists of Fourier analysis of the experimental data using autocorrelation techniques in a digital computer. The most significant feature of this method is that the signal-to-noise ratio improves in direct proportion to the length of the experimental record analyzed.

An existing computer program has been modified to perform the autocorrelation and Fourier analysis calculations. To test the method of analysis, short experimental records of data from tin were recorded on punched cards and analyzed. These tests indicated that the analysis system worked as expected. Work is now in progress to add the capability of analyzing arbitrarily long experimental runs recorded on magnetic tape and thereby achieve the maximum possible signal-to-noise improvement. The additional computer programming required for the magnetic tape data is nearly complete at this time.

Publications

1. McDonald, D. G., The de Haas-van Alphen Effect in Niobium, JPL Space Programs Summary 37-30, Vol. IV., December 31, 1964.

2. McDonald, D. G., "The de Haas-van Alphen Effect in Niobium," Bull. Am. Phys. Soc., Vol. 10, 605 (1965). (Presented at June 1965 A.P.S. Meeting in New York, N. Y.)

Page Intentionally Left Blank

MAGNETICS RESEARCH
NASA Work Unit 129-02-05-06
JPL 329-21401-1-3450

During the past 6 mo, work in the magnetics area has been devoted mainly to the assembly of a superheterodyne spectrometer for the 10 to 100 Mc range. This spectrometer will have frequency stability better than 1 ppm, frequency modulation, double frequency conversion, and phase-sensitive detection. It will be capable of operation with specimen temperatures in the range from 4.2 to 300°K; however only 4.2°K (liquid helium) and 0°C (ice water), and perhaps 90°K (liquid oxygen) will be used for measurements because of the stability and reproducibility of these temperatures. The necessary parts for the spectrometer have been ordered and the assembly has been started. Because of the delay in the delivery of some parts of the equipment, the completion of the spectrometer is not expected before October 1965.

The spectrometer will be used to study the nuclear magnetic resonance (NMR) in fine particles of Fe^{57} that are uniformly dispersed in a nonmagnetic binder. The frequency of this resonance is a measure of the internal magnetic field at the site of the nucleus in the ferromagnetic particles. This internal field consists of the molecular field within each particle and the interaction field caused at the location of a particle by its neighbors. When the density of the ferromagnetic particles in the nonmagnetic binder is reduced, the mean distance between them is increased and, consequently, the interaction field is reduced. This will cause a change in the NMR frequency of the Fe^{57}. Because the molecular field in ferromagnetic materials is of the order of 10^6 oersted while the interaction field is between 0 and 100 oersted, the change in NMR frequency will be small (a few parts per million); which puts the strict requirement on the frequency stability of the spectrometer. Again, the limited natural abundance of Fe^{57} (i.e., 2%) limits the strength of the output signal and requires extreme gain with high signal-to-noise ratio. The first material to be studied will be iron oxide; however, other possible materials have been considered and will be studied later. It is expected that the spectrometer will permit the direct measurement of the strength of the interaction between particles as a function of their density, and thus enable us to determine the highest possible density of digital magnetic information storage without mutual interaction between the different bits.

THERMOELECTRIC THIN FILMS

The electrical transport properties of thin metal and semimetal films are to be studied. Thermoelectric, resistive and Hall effect measurements will be made in the temperature range from 1.6 to 425°K for films grown on crystalline and noncrystalline substrates. The electrical transport properties of copper, bismuth, antimony, and tellurium films will be studied as a function of film thickness. The conditions required for achieving bulk properties will be determined. In addition, the electrical transport properties of films formed from compounds and alloys of the above metals with each other and with other metals will be studied. The effect of compounding and alloying on the transport properties will also provide an understanding of the band structure of the metals and semimetals.

The resistance of a few bismuth films was examined during the early part of the present report period to see if bulk electrical resistivity could be obtained. These films were vapor-deposited in a borrowed vacuum system. The films had a resistivity two to three times greater than the bulk value and, also, a negative temperature coefficient indicating bulk properties had not been achieved.

A vacuum system to be used exclusively for growing films for this work will be received some time in July. The conditions necessary for achieving bulk properties will be obtained and all films will be vapor-deposited in this new vacuum system.

Construction of a system for measuring the thermoelectric and resistive properties of the films was begun in the early part of the report period. Because the scientist involved in this work was away during March, April, and May (performing an Army R. O. T. C. commitment), this system was not completed. It is expected to be completed in July.

An important result expected in this work is the achievement of thin films having higher thermoelectric output and lower resistivity than the films now used as thermoelectric infrared detectors.

PUBLICATION

Wilts, C. H., Ferromagnetic Hysteresis Instrumentation, p. 58, JPL Space Programs Summary 37-32, Vol. IV.

HIGH FIELD SUPERCONDUCTIVITY
NASA Work Unit 129-02-05-08
JPL 329-21501-1-3280

The aim of this program has been to study the superconducting critical current density properties of Type II superconductors, such as Nb, Ti, and Nb_3Sn, in fields in the range of 50 to 100 kilogauss. A 100 kilogauss Bitter/LeRc-type solenoid was constructed at JPL for these studies. Data were obtained on Nb_3Ti samples with no cold working, which indicated that these samples were superconducting at 100 kilogauss. This represents the first information obtained on Nb_3Ti at this high field. Experiments were started on Nb_3Sn samples with various impurities added to study their affects on critical field and critical currents.

The ripple in the unipolar generator, which is used to excite the solenoid, was so great (1-2%) that it invalidated many of the Planned Type II superconducting experiments. Extensive attention to the problem resulted in the ripple being reduced about two orders of magnitude, to four parts in 10^4. This was done by filling the NaK sumps in the generator to a higher level than had been previously used. (The NaK acts as a commutating fluid in the generator.) In addition, the manufacturer's service man worked on the generator to replace several seals that had worn in the NaK pumps. After these repairs, the generator and magnet were tested at high magnetic field values in preparation for superconductivity experiments. During these tests the solenoid's electrical resistance was lower than on previous tests and the magnetic field was less than it should be for the current through the solenoid. This showed that a short circuit between several turns had occurred in the solenoid. Later disassembly of the solenoid confirmed this inference. Extensive investigation of the damage to the solenoid showed there was a defect in the copper of one of the turns and that this defect caused excessive ohmic heating. This heating, in turn, caused a spacer between turns of the solenoid to fail, which resulted in a short between turns. A more detailed report of the failure of the solenoid is covered in an internal memo dated May 27, 1965, "The Failure of the JPL 100-Kg Magnet." Because of the damage to the solenoid it was felt a new solenoid would have to be made.

An order for the purchase of a new copper billet has been started. The new solenoid will be constructed in-house at JPL in a manner similar to the damaged solenoid. The design of the new solenoid has been changed so more cooling water will be available, and the thickness of each turn will be increased to give more strength to the solenoid. In addition, a new spacer material will be used and the spacers will be thicker. Also, twice as many spacers will be used in the construction. This new design should greatly reduce the probability of a failure of the solenoid similar to the difficulty that was experienced with the damaged solenoid.

Dr. Hildebrandt and Dr. Elleman visited Dr. Boom at Atomics International and discussed in detail the Type II superconductivity experiments that are under investigation. Future collaboration with the people at Atomics International is planned.

The Type II superconductivity work unit will be discontinued because of a manpower reduction. However, the 100 kilogauss magnet and its auxiliary equipment will be used in the Low Temperature Physics program, mainly for de Haas-van Alphen effect experiments and nuclear magnetic resonance studies.

Page Intentionally Left Blank

SEMICONDUCTOR RESEARCH
NASA Work Unit 129-02-05-09
JPL 329-21801-1-3450

SPACE-CHARGE-LIMITED CURRENT IN GERMANIUM

During the report period, several $n^+\pi n^+$ solid-state diodes were fabricated. Junction I-V characterizations, and punch-through voltage measurements were made to evaluate the electrical properties of these alloyed solid-state diodes. The results indicate that solid-state diodes of various punch-through voltages, and with excellent reverse-biased junction electrical characteristics, can be readily fabricated. However, there appears to be an inconsistency between sample base-widths as calculated from the I-V characteristic and the punch-through voltage, which is now being resolved by metallurgical analysis of the junction regrowth surfaces of the alloyed regions. Preliminary metallurgical observations show that the regrowth surfaces of the alloyed regions exhibit a grain structure. Improvements in the alloying techniques are being introduced to eliminate this type of regrowth. A metallurgical cross-section of one sample was made and the junction boundaries displayed by a chemical etchant were flat and parallel.

A chemical hood for cleaning and etching of the solid-state diodes and a clean station for a dust-free environment were installed. A vacuum evaporator will be purchased during the next report period for vacuum deposition of masks and alloying material onto the π-type germanium wafers.

During the next report period, metallurgical observations (on more solid-state diodes) will be performed to resolve the base-width calculation inconsistency and to improve the alloying operation. A systematic electrical characterization of all fabricated solid-state diodes will be made to determine geometrical and electrical symmetries of the junctions. Measured space-charge limited-electron current at various ambient temperatures (26 to -195°C) will be evaluated and compared with the results already obtained for the hole current. Bulk minority charge carrier drift mobility measurements of the Shockley-Haynes type in the π-type germanium will be made. The n^+ and the p^+ alloying technologies already developed and used individually at JPL will be exploited together to fabricate $n^+\pi p^+$ structures that are very useful for studying two carrier space-charge-limited current.

TITANIUM OXIDE THIN FILMS

The purpose of this investigation has been to explain the mechanisms of electronic conduction and charge storage in titanium oxide thin films. It is anticipated that this will also lead to a better understanding of other insulating or semi-insulating thin films because they share many similar properties. The absence of a satisfactory theory for explaining much of the related experimental work in the literature, dating back many years, has required that this study place particular emphasis on the formulation of such a theory. To develop the physical basis of the theory, it was necessary to obtain reliable experimental data with which to make comparisons. Therefore, the initial phase of this work has been to accumulate the necessary experimental data and this has been followed by a critical search for a consistent theoretical explanation.

The initial experimental work was performed in most part prior to the report period, with only certain supplementary data being added during the period. A description of the experimental method used in this program has been reported (Ref. 1). Additional work performed by the principal scientist before the formation of the program at JPL has also provided useful data (Ref. 2). During this report period, several physical models were examined to seek a theoretical basis for explaining the experimental results previously obtained. More specifically, a mechanism was sought that would account for the observed electrical properties in thin film samples of metal-titanium oxide-metal sandwich configurations, and that would also be consistent with the other measured properties. It is believed that this effort has been successful because the physical model derived does provide a consistent overall picture of the results and has survived more exacting quantitative tests so far. The basic ideas for the physical model, the assumptions imposed, and some theoretical consequences are briefly described below. It may be helpful to first mention two well-known theories that have been applied to thin films with questionable success and then only in certain limiting cases.

One well-known theory involves pure electron tunneling between the metal contacts. This theory can be expected to apply only in extremely thin films (less than the order of 40 Å) and serious departures are found here between theory and experiment. The other theory involves thermionic emission of electrons from the metal over the metal-insulator barrier (often referred to as Schottky emission when the effects of image forces are included). In both theories, the insulating film is conventionally treated almost identical to a vacuum except for appropriate changes in barrier height (metal-insulator work function), dielectric constant, and electron effective mass. The ideal free electron concept is thus assumed valid.

One important consideration about the physical model derived involves the failure of the usual free electron concept. This can arise independent of the structural quality of the films treated (experimentally shown to be quasi-amorphous). This is justified because of the polaron theory developed in recent years, which treats an electron in a polar lattice as a new quasi particle consisting of an electron coupled to a cloud of optical phonons. The effect of strong coupling (which applies here) is to severely reduce the electron mobility and mean-free-path so the electron in the polar lattice can no longer be considered free, but moves very slowly; essentially tied to the conduction band edge (more correctly, to the polaron band). Even if the polaron coupling is not very strong in single crystals, the effect would be greatly enhanced in quasi-amorphous films because of the initial reduction in electron mobility by defect scattering.

Another important consideration involves the effect of high densities of defects or correspondingly high densities of impurity states within a forbidden band. This can lead to large space-charge effects even in very thin films when the occupancy of the impurity states is altered by the presence of metal contacts or applied fields. The titanium oxide films provide an interesting limiting case in this respect. The titanium oxide will quite readily undergo a reversible oxidation-reduction reaction; i.e., $6\ TiO_2 \quad 6\ Ti_2O_3 + \ 3O_2 + (26\ kcal/mole)$. A moderate reduction process applied to bulk single crystals of insulating rutile $(Ti)_2)$, e.g., 15 min at 700°C in H_2, will produce extremely high densities of oxygen vacancies in excess of $10^{20}/cm^3$ that act as donor impurities, converting the rutile into a degenerately doped n-type semiconductor. This effect saturates at about 5 atomic % ($1.6 \times 10^{21}/cm^3$) before structural changes occur. It is reasonable to expect correspondingly high densities of oxygen vacancies to occur in the thin films that are necessarily deposited in the

presence of a low partial pressure of oxygen. This consideration leads to a physical model that treats the TiO_2 films as degenerately doped semiconductors and provides a limiting case for the effect of impurities that can also be important to a less drastic extent in other materials.

The above considerations lead to a band structure for the isolated TiO_2 film such as that illustrated in Fig. 1a. The material as shown is degenerate, i. e., the Fermi level lies slightly above the smeared-out edge of the conduction band. However, the conductivity is extremely low when compared with degenerately doped nonpolar semiconductors such as silicon because of the small polaron mobility, yet sufficiently large to permit excessive conduction in thin films. The presence of metal contacts produces barriers consisting of positive space-charge layers adjacent to the two interfaces as shown in Fig. 1b. The interface barrier height, ν_o (metal to oxide work function), has often been determined from elementary considerations by the difference in the work function of the metal and the electron affinity of the oxide, but usually is fixed by interfacial states. Such a space-charge layer is often referred to as a Schottky barrier, and was the subject of much controversy (in the early 1930's) for metal oxide point contact rectifiers. The theories developed in that period, although closely related to the theory derived in this work, were not carried far enough to account for the conduction processes considered. The large space-charge density assumed here results in very narrow Schottky barriers, of the order of 30 Å; which allows electron tunneling to occur between the metal contact and the oxide interior. Furthermore, the shape of the barrier results in a process intermediate between that of pure tunneling and thermionic emission, and leads to a temperature-dependence in good agreement with the previously unexplained experimental data. This model is seen to result in a structure consisting of two Schottky barriers back-to-back. Under applied voltage, the voltage divides between them and across the interior in such a way as to maintain a constant current through the structure. Either the first or second barrier can dominate depending on the applied voltage and temperature. An interesting dependence of capacitance on temperature, voltage, and frequency results from this model. An equivalent circuit for the structure is given in Fig. 2, which serves to suggest the type of dependence. More complicated situations arise when the two contacts are not equivalent.

A qualitative and semi-quantitative comparison between theory and experiment gives satisfactory agreement, as already mentioned. A more detailed comparison is in process and the results will be given in a future report.

During the report period, the author attended the IEEE-sponsored Solid State Device Research Conference at Princeton, New Jersey. The conference is a closed meeting that discusses only the most recent unpublished research on solid-state devices.

REFERENCES

1. Maserjian, J., Titanium Oxide Thin Films, p. 98, JPL Space Programs Summary 37-31, Vol. IV.

2. Maserjian, J., work performed at CIT for Ph. D. dissertation; to be published.

PUBLICATIONS

1. Shumka, A., Space-Charge-Limited Current in Germanium: Fabrication of Solid State Diodes, p. 64, JPL Space Programs Summary 37-32, Vol. IV.

2. Nicolet, M. A., and Denda, S., Preparation of nπn Structures for the Study of Space-Charge-Limited Current in Silicon, JPL Space Programs Summary 37-33, Vol. IV (to be published).

3. Maserjian, J., Titanium Oxide Thin Films, p. 98, JPL Space Programs Summary 37-31, Vol. IV.

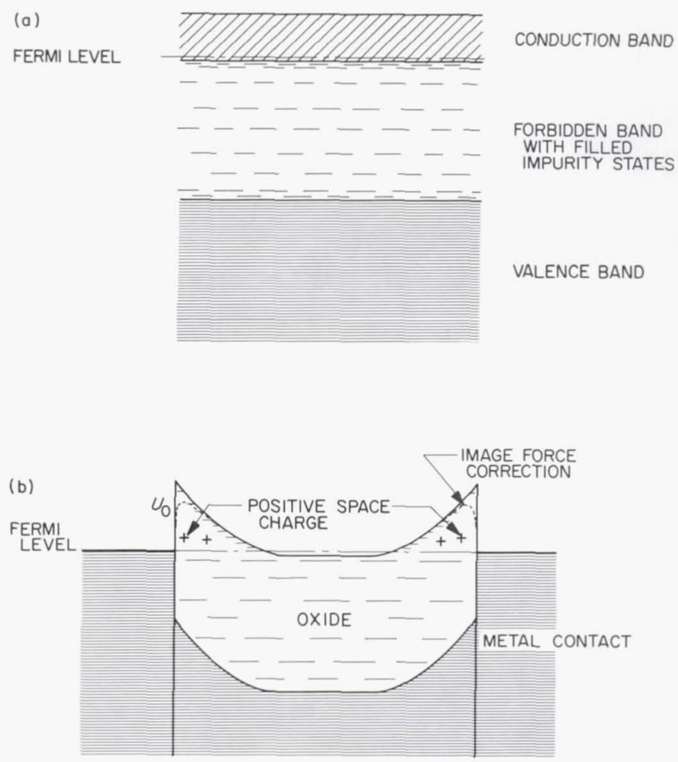


Fig. 1. Energy band diagrams

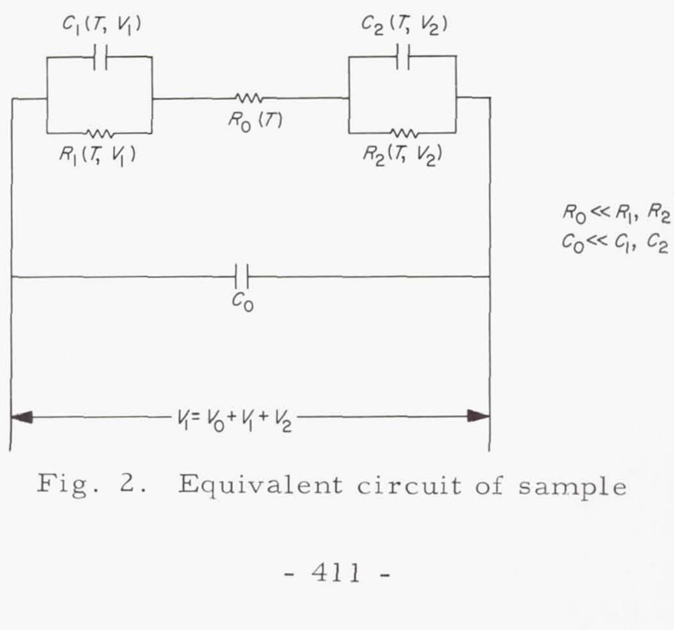


Fig. 2. Equivalent circuit of sample

Page Intentionally Left Blank

THEORETICAL PHYSICS
NASA Work Unit 129-02-07-02
JPL 329-20901-1-3280

The objective of this work is to increase theoretical understanding at the forefront of modern physics. Activities in areas now of interest are described in the following paragraphs.

INTERACTION OF HIGH INTENSITY RADIATION WITH MATTER

This problem, relating mostly to the nonlinear interaction action of laser light with matter, is one now marked by considerable activity and controversy. Problems that have been analyzed by the group are indicated by the following reports and publications:

1. Von Roos, O., Remarks on the Frequency Shift in High Intensity Compton Scattering, JPL Space Programs Summary 37-31 Vol. IV, Feb., 1965.

2. Von Roos, O., Double Compton Effects with High Intensity Radiation, submitted for publication.

3. Von Roos, O., *Theory of Ionization of Atomic Systems by High Intensity Radiation*, JPL Space Programs Summary 37-33, Vol.IV.

4. Saffren, M. M., Interaction of Intense Electromagnetic Beams with Electron Beams, JPL Space Programs Summary 37-33, Vol. IV.

PLASMA PHYSICS

Plasma physics studies, a collaborative effort between C. -S. Wu and E. H. Klevans, are described under the Plasma Physics Research task (NASA Work Unit 129-02-03-03).

RELATIVITY

A new algorithm for dealing with space-time geometry, devised by Estabrook and Wahlquist, continues to be applied to a variety of problems in general relativity. Efforts during the report period have resulted in two invited talks presented at an International Conference on General Relativity, London, June 1965:

1. Estabrook, F. B., "Measurement of Gravitational and Inertial Fields in General Relativity."

2. Wahlquist, H. D., "Rigid Motions in Einstein Space." (See, also, JPL Space Programs Summary 37-32, Vol. IV, Feb. 1965.

SUPERCONDUCTIVITY

A rather complete treatment of the physics of rotating superconductors has resulted from analysis of the experiments performed last year by A. Hildebrandt (Low Temperature Physics Task). This is given in the following reports:

1. Saffren, M. M., The Rotating Superconductor I: The Fluxoid, JPL Technical Report No. 32-650 (Part I), March 15, 1965.

2. Saffren, M. M., The Rotating Superconductor II: The Free Energy, JPL Technical Report No. 32-650 (Part II).

3. Saffren, M. M., The Rotating Superconductor III: The Super-electrons as an Incompressible Charged Fluid, JPL Technical Report No. 32-650 (Part III), May 31, 1965.

4. Saffren, M. M., London's Equation as an Expression of Larmor's Theorem, JPL Space Programs Summary 37-31, Vol. IV, Feb. 1965.

5. Saffren, M. M., The Superconducting Transition of a Hollow Cylinder Rotating in a Magnetic Field, JPL Space Programs Summary 37-32, Vol. IV, May 1965.

ELEMENTARY PARTICLE THEORY

A clarification of an important group-theoretical point is reported by M. M. Saffren in Space Time Symmetry and Mass Splitting, JPL Space Programs Summary 37-32, Vol. IV, May 1965.

An ambitious program by J. S. Zmuidzinas, to provide a very basic and unified description of elementary particles has resulted in several manuscripts in various stages of preparation for publication. A summary of this effort follows.

The objective is to construct a theory of elementary particle symmetries and dynamics based on a minimum of axioms, namely, quantum mechanics, and special relativity. (One difference between this and other theories is that we do not assume the existence of internal symmetries but propose to prove it.)

The first basic (physical) idea of the theory is that particles occurring in nature are compound systems of infinite complexity. This is implied by the bootstrap hypothesis widely accepted by physicists at the present time.

The second basic (mathematical) idea is that every measurable quantity in particle physics should be calculated by the methods of quantum mechanics by exploring the consequences of the special theory of relativity to a much greater extent than it has been done before; in summary: everything from space-time through quantum mechanics.

Attempts to construct geometrical theories of particles have been made by many people. None of them have been fully successful.

During the past 6 mo, this much has been accomplished. A mathematical formalism has been constructed based on the physical and mathematical ideas. It has been possible to derive a hierarchy of internal symmetry groups with their associated quantum numbers (baryon number, electric charge, strangeness, etc., all properly quantized, of course). The results will be given later in a Laboratory report. A condensed (and somewhat modified) version of the report will be submitted for publication.

The kinematical aspects of the theory thus being essentially completed, the next step is to consider dynamics. As necessary mathematical preparatory work for this, we have completed a manuscript on representations of the (restricted) Lorentz group on four-vector manifolds that will be submitted for publication. An oral presentation of this work is planned to be given at the joint meeting of the American and Japanese Physical Societies to be held in September at Honolulu, Hawaii.

Our future plans are the following. First, we shall investigate the simplest dynamical model within the framework of our theory and shall try to understand its workings in terms of conventional field theory and/or S-matrix theory. If and when the simple model is physically rather well understood, we shall proceed to generalize it to more complex physical cases. Initially, we hope to have a dynamical scheme for strong interactions; eventually, for the weaker ones.

We may remark that one way of proceeding with the dynamical calculations is to extract the scattering amplitude (T-matrix) from the solutions of a certain radial equation, the relativistic analog of the Schrödinger equation. All quantities of physical interest, including bound state masses, coupling constants, etc., are contained in the T-matrix.

Page Intentionally Left Blank

MATERIALS RESEARCH (129-03)

SPACECRAFT METALS
NASA Work Unit 129-03-02-01
JPL 329-30101-1-3510

The objective of this work was to determine the effects of various pretreatments, alloying, and methods of processing on the basic behavior of well characterized tungsten at temperatures above 2500° F. Early in the reporting period it was decided that this work would not be continued beyond the end of the fiscal year. Therefore, the major effort during this period has been directed toward the completion of the experimental work in progress and the preparation of technical reports giving the results obtained.

The unreported data and the conclusions reached from a study and analysis of these data are being presented in three technical reports. A brief abstract of each of these is given here, the complete reports should be available about September 1, 1965.

1. Tensile Properties of Tungsten-2% Thoria from 2500 to 5400° F in Vacuum. (This manuscript has been submitted for publication to the quarterly *Transactions of the American Society for Metals.*)

The tensile properties of tungsten containing 2% thoria were measured at temperatures from 2500 to 5400° F. Stress-strain curves were obtained at a strain rate of 0.02/min in vacuum. At 4500° F, recrystallized tungsten-2% thoria is the strongest metallic material reported in the literature to date, and its strength at 5000° F is 5000 lb/in^2, twice as great as for tungsten-3% rhenium or commercial doped tungsten. Ductility is low, elongation and reduction in area being less than 5% above 3500° F. Microstructures of the tungsten-2% thoria showed coarse interlocking grains and intragranular fracture with some fracture along sub-boundaries. The interlocking grains coupled with the presence of dispersion-strengthening particles of thoria appear to account for the high strength and creep resistance at very high temperatures.

2. Tensile Behavior of Same-Lot Single-Crystal and Polycrystalline Tungsten from 2500 to 5000° F

Tensile specimens machined from Type MK powder-metallurgy swaged tungsten rod were heated for 10 min at 5150° F in a vacuum of 1×10^{-5} torr or less. About 20% of the specimens so treated grew single-crystal cores large enough to encompass the entire gage section of the test specimen, while the remainder of the treated specimens were wholly polycrystalline. The tensile properties of both single- and polycrystalline-material of the same lot were measured from 2500 to 5000° F under the same experimental conditions.

The single-crystal specimens showed a definite perferred orientation. Over 85% of these specimens were oriented so as to be included in a circle of 12 deg radius centered approximately at latitude 6° N and longitude 2° E in the stereographic unit triangle. The tensile properties of these single-crystals were found to be orientation dependent. Orientations near $[001]$ are favorably oriented for $\{112\}$ $\langle 111 \rangle$

and {123} ⟨111⟩ slip while those orientations between ≃ 20 and 33 deg from [001] on the [001] - [011] join are favorably oriented for {110} ⟨111⟩ slip. Favorable orientation for a particular slip system is based on calculated critical resolved shear stress boundaries that were confirmed experimentally as discussed in another part of this review. Orientations near the [001] corner of the unit triangle were the strongest at temperatures up to 4000° F and the most ductile at all temperatures in the range tested. A minimum in the elongation vs temperature curve appears between 3500 and 4000° F for crystals oriented for {110} ⟨111⟩ slip.

It is inferred that swaged recrystallized polycrystalline tungsten rod has some degree of preferred orientation from the orientation of the seed crystals in the core that grow into single crystals of preferred orientation during heat treatment. The ductility minimum, indicated by low values of elongation and reduction-in-area, for most recrystallized powder-metallurgy tungsten materials (tested at low strain rates) occurs between 3000 and 4000° F. This minimum in the polycrystalline material may be related to the preferred orientation. The preferred orientation texture for this lot of tungsten is not the one usually found for swaged recrystallized bcc metals, which is stated to be [110].

3. Slip in Tungsten from 2500 to 5000° F

This study of the slip in tungsten at high temperatures was undertaken as an extension of the previously mentioned study of the tensile behavior in single-crystal tungsten. Noncrystallographic slip as well as three temperature-dependent slip modes or familes {110} ⟨111⟩, {112} ⟨111⟩, and {123} ⟨111⟩ have been reported for bcc metals in tension. Tungsten, being a bcc material, could possibly show any of these modes of slip behavior and there is disagreement among previous investigators about which modes are operative at high temperature. The {112} ⟨111⟩ and {110} ⟨111⟩ slip have each been reported as being the only operable family at high temperature with no one reporting evidence of the {123} ⟨111⟩ mode. The present work gives evidence showing that, over the temperature range studied, all three families can be operative. These findings are in good agreement with the regions of slip which can be defined within the unit stereographic triangle by calculating critically resolved shear stress from the crystal geometry. These regions are shown in Fig. 1.

The orientation of the single crystal specimens was determined optically by reflections from {110} planes that were exposed as etch pits by macroetching in a sodium hydroxide-potassium ferracyanide solution. Slip planes were determined by a modification of the trace-in-two-surfaces method. The angle between the visible trace of the slip plane and the rod axis was measured as the specimen was rotated and translated along its axis. The two angles plotted on a sterographic net give the orientation of the pole of the slip plane, which is then referred to stereographic projection of the crystal. The phenomenon of overshooting was observed for several orientations. Overshooting refers to slip that continues in the same direction even though a critically resolved shear stress boundary is crossed (i.e., another slip system should operate and, therefore, another slip direction should be observed). Three examples of overshooting may be seen in Fig. 2. Crystals 1-18 and 1-10 have exhibited slip across the [001] - [011] join where conjugate slip on another (110) place should occur. Without overshoot, slip would normally continue along the [001] - [011] join to [011]. In Fig. 2 the solid symbols represent orientation of deformation bands in the matrix of the strained gage section. The optical method

was readily applied to the determination of the orientation of selected fine areas at 100X. No explanation is offered for the direction of movement of the deformation bands during strain, however; in general, the orientation of the bands appears to move backward along the great circle joining the original orientation and the slip direction.

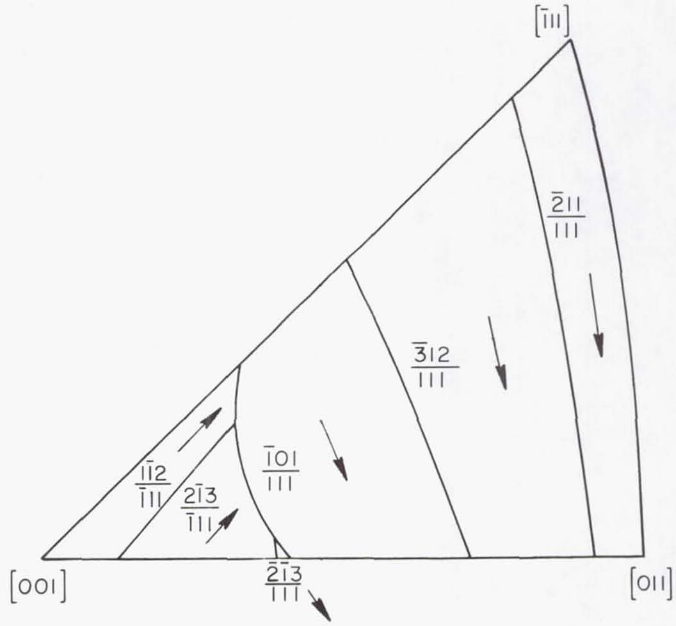


Fig. 1. Regions of slip

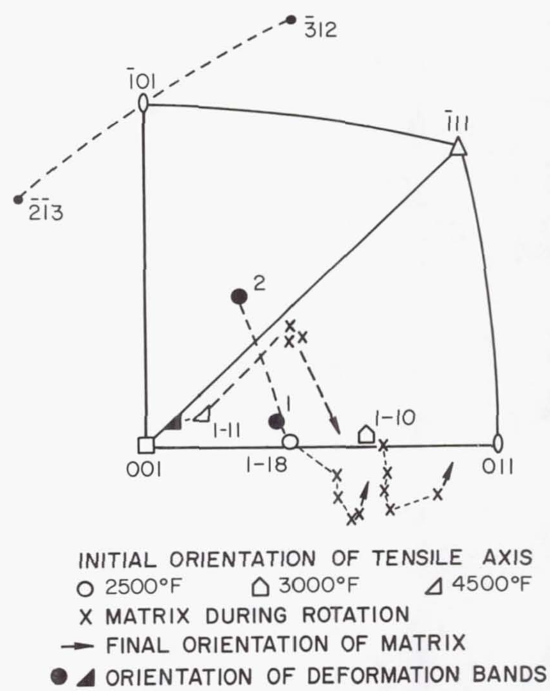


Fig. 2. Three examples of overshooting

Page Intentionally Left Blank

CERAMIC MATERIALS
NASA Work Unit 129-03-04-01
JPL 329-31101-1-3510

MECHANICAL BEHAVIOR

The present ceramic research is being directed toward the understanding of the role of grain and associated impurities in the deformation and fracture of polycrystalline ceramics. Such information is vitally needed to find out the failure mechanism of real ceramics and so design the microstructure to reduce failure rate.

The primary effort during this report period has been placed on the completion of the test facility for determination of the mechanical behavior of ceramic materials. The test frame[1] has been set up and is operating. The strain measuring system, based on two optical trackers[2], has been installed along with the associated back lights and power supply. An electronic panel has been completed for adjusting the signal level and sensitivity of the strain system and to provide outputs for data recording. A special load cell using dual range capability to provide full scale deflection for loads from 2 to 1000 kg has been designed and constructed.

The spherical gas bearings designed to reduce misalignment in the load train have been operated. The gas supply for the bearings will be completed on receipt of special constant flow regulators and a high pressure supply. Initial alignment of the bearings has been completed but will be repeated after installation of the new load cell and movement of the entire facility to a new location. A water-cooled environmental chamber has been installed; however, water connections, vacuum pumps, and valving will be installed after relocation. Figure 1 shows the present configuration of the facility.

Three independent furnaces to be interchangeably installed in the environmental chamber have been designed and constructed. The furnaces, all resistance heated, offer the following capabilities: (1) a nickel-chrome alloy furnace for operation to 1200°C in oxidizing environments, (2) a molybdenum strip furnace for operation to 1700°C in a nonoxidizing environment, and (3) a graphite furnace for operation to 2500°C in an inert gas atmosphere. These furnaces use a clam-shell design to permit ease of specimens loading. Power supplies have been designed and have in part been purchased and installed. Space limitations require the remainder to await relocation of the facility.

During the next report period, the set up and evaluation is expected to be completed if the facility is moved to its new location during the early part of the period. The evaluation will include: (1) calibration of stress and strain detection system; (2) calibration of temperature measurement, distribution, and control systems; and (3) evaluation of nonaxial stresses.

The development and fabrication of test specimens for the determination of mechanical properties has continued. Difficulty was encountered in locating vendors

[1] Instron Engineering Corporation, Canton, Mass.

[2] Optron Corporation, Santa Barbara, California

capable and willing to attempt the fabrication of the precise and complex contour required to reduce notch effect in the brittle ceramic specimens. Two sources have been located and their capabilities are being evaluated. Approximately 12 Magnesium Oxide specimen blanks have been fabricated and six of them are being ground. Some specimens have fractured during grinding operations and the cause for this fracture is being evaluated.

Studies have been continued to determine the detailed nature of the grain boundary. Electron micrographs (Fig. 2) have been obtained that suggest the grain boundary region can occupy a significant volume in a fine-grained polycrystalline ceramic. Further, additional evidence for grain boundary segregation has been obtained by means of an electron microprobe studies. Figure 3 shows a region in 99.5% pure Magnesium Oxide in which the impurities have been segregated into two separate phases existing at the grain boundaries. Similar behavior has been noted in higher purity material, the primary difference being a smaller quantity of segregated material. Work on the determination of the nature of grain boundary will continue during the next period.

A theoretical evaluation of the nature of the grain boundary is to be undertaken. It will be based on a model similar to those evolved for the structure of glasses. Attempts will later be made to incorporate this model into the mechanical behavior.

A recently published article (Ref. 1) has provided one theory for the role of grain boundaries in mechanical behavior of ceramics. A brief abstract of this theory is informative because it indicates the type of relationship expected to be obtained in this research. However, the details of the theory to be developed here mav differ considerably as well as being quantitative rather than qualitative. The general nature of this recent theory is shown in Fig. 4 and consideration of two examples would indicate its salient features. Always, it is assumed that real polycrystalline ceramics contain cracks from fabrication and processing that are one grain diameter in length. If such a ceramic of grain size A is stressed, Griffith-Orowan theory predicts failure at point 1 of Fig. 4. At this stress the crack, if its tip radius were controlled by lattice dimensions, would propogate catastrophically. Real ceramics, however, generally require a higher stress (point 2 of Fig. 4) for failure. The theory proposes that the real crack lies with its tip in a grain boundary where it has been blunted by inferior bonding and flow of the grain boundary material. Griffith-Orowan theory predicts a higher stress for propogation of such blunted cracks. If a ceramic of grain size B is stressed, blunted cracks again permit stress above point 3 (Fig. 4); but at point 4 (Fig. 4), the yield stress is reached and the blunted crack yields into the next grain, sharpens and catastrophically propagates. At very fine grain sizes, C, fracture should not occur until even higher stresses (point 5 of Fig. 4) are reached because even cracks that have yielded and sharpened will not be of critical length.

Throughout this grain size region, failure may occur by grain boundary deformation if the temperature is high enough to permit this process to occur. Failure by this process, if possible, is indicated by the line labeled "grain boundary sliding."

During the previous report period, JPL Technical Report 32-736 titled "Fabrication of High-Purity Polycrystalline Magnesium Oxide" has been published. A modified version of this report has been submitted to the Bulletin of the American Ceramic Society. The Manuscript titled "Mass Spectrographic Analysis of

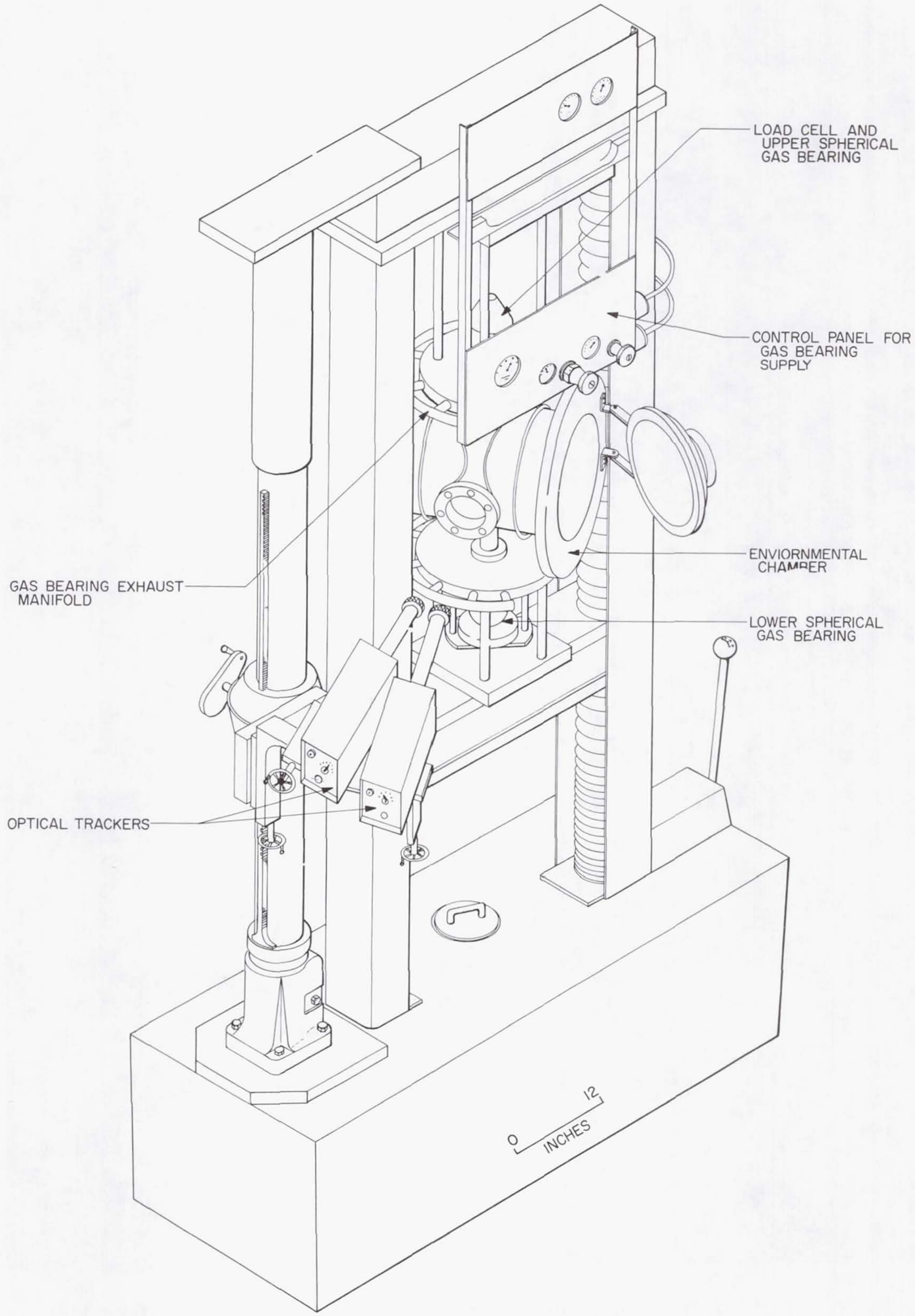


Fig. 1. Mechanical test facility for determination of mechanical properties of ceramic materials

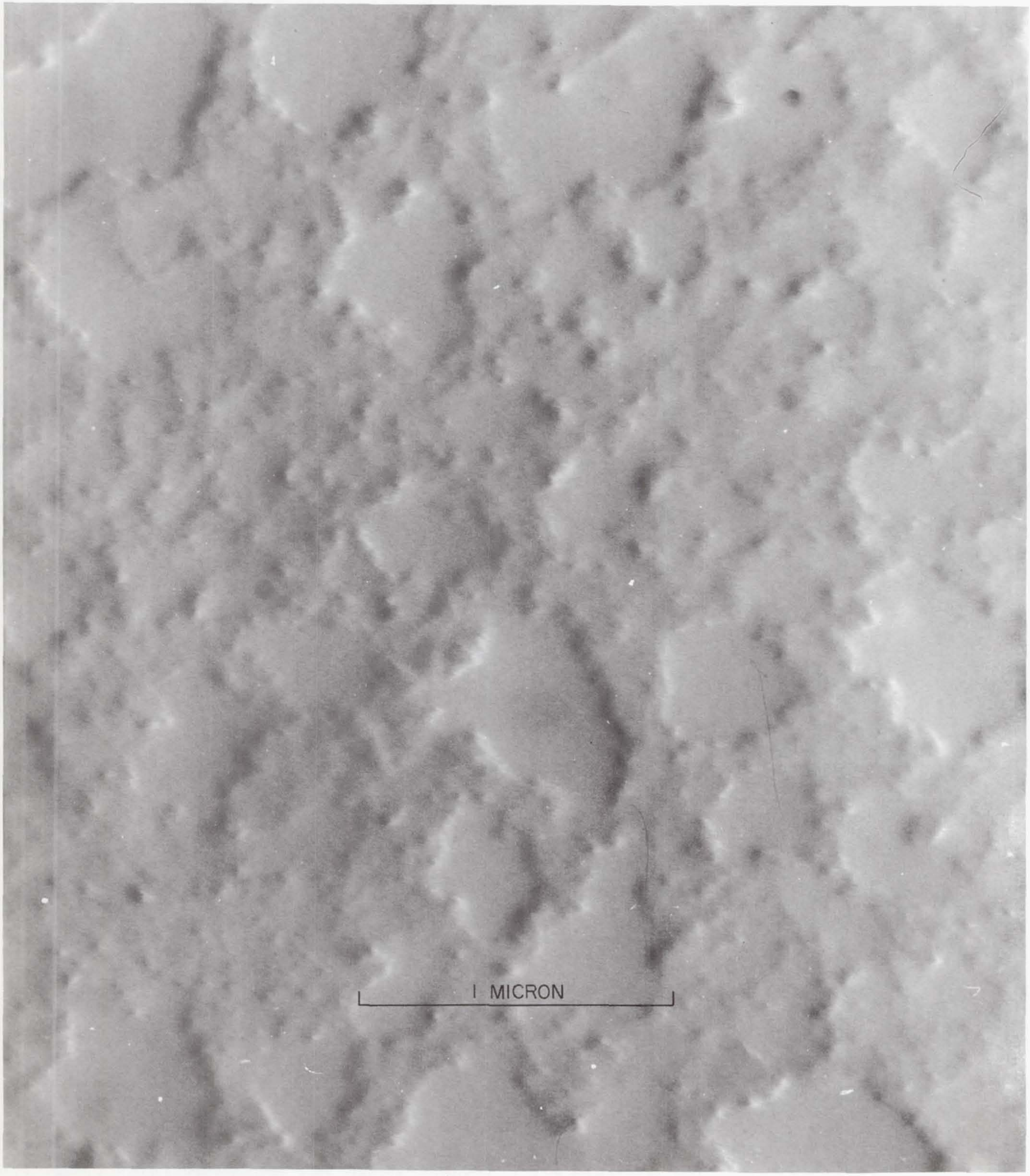


Fig. 2. Electron micrograph of high-purity magnesium oxide. Hot pressed at 750°C and 20,000 lb/in.^{2} for 1 hr in air. Density = 3.575 g/cm^3. Steam etched and dual replicated

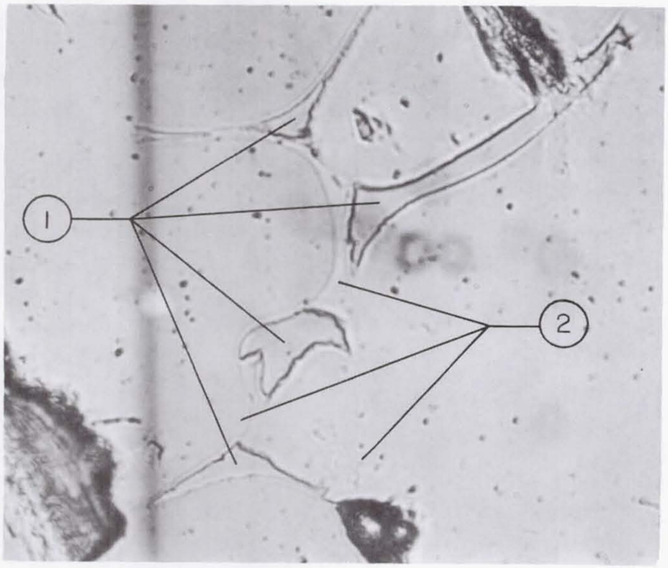


Fig. 3. Region of impurity segregation at grain boundaries in 99.5% pure magnesium oxide after reheating to 2200°C for 1 hr in oxygen

(1) $(Ca_{0.5}Mg_{0.5})O \cdot SiO_2$
(2) $Al_2O_3 \cdot 3\ MgO$

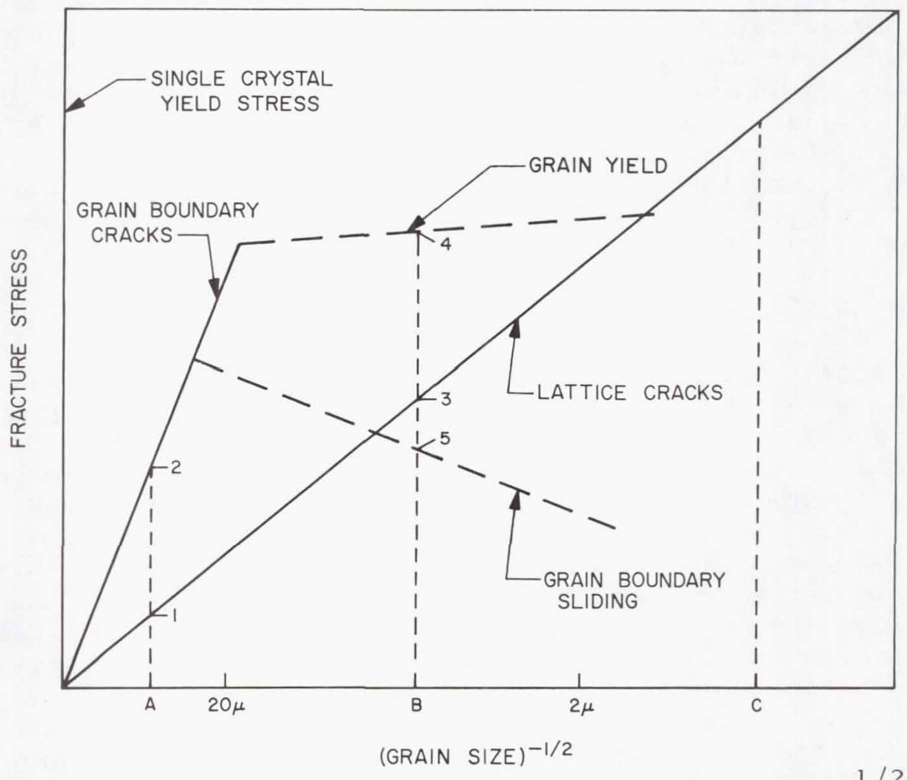


Fig. 4. Theoretical fracture stress vs. (grain size)$^{-1/2}$ for polycrystalline ceramics

Nonconducting Ceramics" has been accepted for publication by the Journal of the American Ceramic Society. When reprints are available it will be issued as a JPL technical report. During the next 6-mo period a paper will be started on impurity segregation in Magnesium Oxide.

Technical effort has been continued by Sperry Rand Research Center on JPL Contract 950992 toward the development of improved analytical techniques for use with refractory materials. A survey of the applicable techniques has been made and evaluated. These results have suggested that solid source mass spectroscopy will provide an efficient return of information. Techniques for its use are being developed. In addition, hydrogen fusion analysis is being evaluated as a means of determining hydroxyl concenrations. Present emphasis in both these techniques is on the development of meaningful bulk analyses. The problem of impurity distribution, although vitally important, must await completion of this initial phase.

During this period technical assistance was provided at the reviews of NASA research grant No. NSG484 at the University of Washington and NASA contract NAS7-276 with the Boeing Corporation. Both of these programs are under the technical management of James J. Gangler.

Professional meetings and discussions held concerning this task involved: (1) discussions with the staff and students of the Metallurgy and Ceramics Departments of the University of Washington on April 26, and presentation of a seminar titled "Role of Grain Boundaries in Materials" to these groups, (2) discussions with Hubert Probst, Myron Davies, and William Sanders at Lewis Research Laboratory on May 7, (3) discussions with E. L. Hodge at Battelle Memorial Institute concerning hot isostatic pressing on May 6, and (4) attendance at the Annual Meeting of the American Ceramic Society. During the next period, the Gordon Research Conference on Solid Studies in Ceramics will be attended and a paper titled "Impurity Segregation in MgO" is to be submitted to the Western Regional Meeting of the American Ceramic Society.

CARBONS AND GRAPHITE

The program for FY 1965 was comprised of studies on the tensile properties of various carbons and graphites prepared by new and unusual methods; and studies on the mechanism of the large high temperature ductility observed in pyrolytic carbons (pyrolytic graphites). Midway through the year the organization and content of the carbon and graphite research program was critically reviewed. To make the most effective use of the limited manpower available for this task, it was decided to concentrate efforts on a smaller number of projects. Primary emphasis was placed on studies of the fundamental mechanisms of high temperatue deformation and failure, and on the kinetics and mechanism of the graphitization transformation. The investigation of unusual carbons has been limited to a single material, Japanese glassy carbon, on which studies were already in progress. Investigations on high temperature deformation mechanisms have been concentrated on pyrolytic carbons. Basal plane shear deformation and the microstructural changes accompanying high temperature tensile deformation parallel to the substrate have been studied. Studies on graphitization are reported under Solid State Materials Research.

Glassy Carbon

Glassy carbon is an impermeable, isotropic, nongraphitizing carbon with a low bulk density (1.5 g/cm^3). Two grades, GC-20 and GC-30, were investigated. According to the manufacturer[1], the GC-20 had been heat treated to a maximum temperature of 2000°C, while the GC-30 had received an additional treatment at 3000°C. Good high temperature tensile properties were found for both grades, especially on a strength per unit weight basis (Ref. 2). As shown in Fig. 5, the isotropic glassy carbons compare very favorably with more familiar anisotropic carbons and graphites on this basis.

Although the ultimate strength of both glassy carbon grades was the same within experimental scatter, the fracture elongation of GC-30 ($\leq$ 5.5%) was much smaller than that of GC-20 ($\leq$ 33%) above 2200°C. Both showed a strength maximum near 2500°C and GC-20 showed a ductility maximum near 2700°C. It was thought that these differences in mechanical behavior might be associated with microstructural differences such as microcrack distribution. The macroscopic appearance of the fracture surfaces was brittle and glassy for both grades at all test temperatures (20 to 2900°C), but electron micrographs of the fracture surfaces (two-step replica technique) revealed characteristic differences in fracture mode as a function of grade and temperature, as shown in Fig. 6a (Ref. 3). Electron micrographs of unetched polished sections of as-received and tensile deformed samples, however, revealed no systematic differences as a function of either grade or deformation temperature. Typical polished section micrographs are shown in Fig. 6b. No microcracks were observed. The only prevalent feature, other than polishing scratches, was a random array of fine pits with an average diameter of about 350A (also visible in the fractographs of Fig. 6a.) If the most sharply defined of these pits are assumed to be pores, the low bulk density of glassy carbon can be accounted for. However, there is a good possibility that the pits are replication or polishing artifacts and the porosity of this material is on a much finer scale. Thus, the micrographic studies have revealed differences in fracture mode of GC-20 and GC-30, but the reasons for these differences remain unknown.

Detailed understanding of the properties of glassy carbons is seriously hindered by lack of information on the raw materials and processes by which they are made. This information is considered proprietary by the manufacturer. Nevertheless, the basis of the unusually good high temperature strength may be inferred from what is known about these carbons. X-ray and magnetic suscepitbility studies (Ref. 4) here have confirmed that the glassy carbons do not graphitize appreciably, even at very high temperatures (1 hr at 3200°C). The generally accepted structural model for nongraphitizing carbons consists of small disordered crystallites, randomly oriented and joined together by crosslink bonds (e.g., tetrahedral carbon-carbon bonds). This isotropic bonding component increases the interlayer shear and intercrystallite boundary strengths, resulting in good microscopic strength which is transferred to the macroscopic sample by processing methods that keep the pore size very small. A major result of the present studies on glassy carbons is the demonstration of the good mechanical properties that can be achieved with properly prepared nongraphitizing carbons. Further development of crosslinked carbon technology may be a fruitful direction to pursue to obtain specialty carbons with improved strength properties. An oral paper on the glassy carbon studies was presented at the Seventh Biennial Conference on Carbon in Cleveland, Ohio, June 1965.

---

[1] Tokai Electrode Manufacturing Company

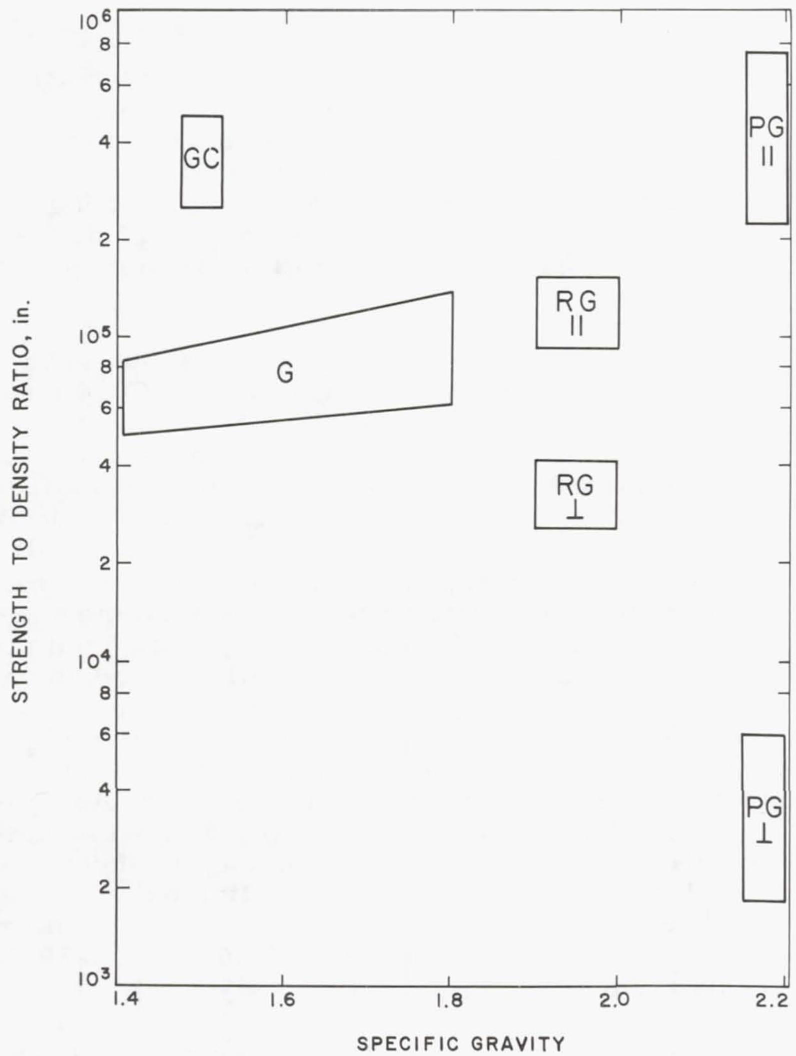


Fig. 5. Tensile strength (at 2500°C) to density ratio as a function of specific gravity. GC = glassy carbon; G = conventional pitch coke graphite; RG || = recrystallized ZTA graphite, stress parallel to grain; RG ⊥ = recrystallized ZTA graphite, stress perpendicular to grain; PG || = pyrolytic graphite, stress parallel to substrate; PG⊥ = pyrolytic graphite, stress perpendicular to substrate.

Basal Shear Deformation of Pyrolytic Carbons

Shear and cleavage parallel to the basal plane are important components of the deformation and failure of graphitizing carbons and graphite. However, very little is known about this deformation mechanism. Investigations on the shear behavior of pyrolytic carbons parallel to the deposition plane have been carried out to obtain information on the dependence of this mode of deformation on temperature, strain rate, and microstructure.

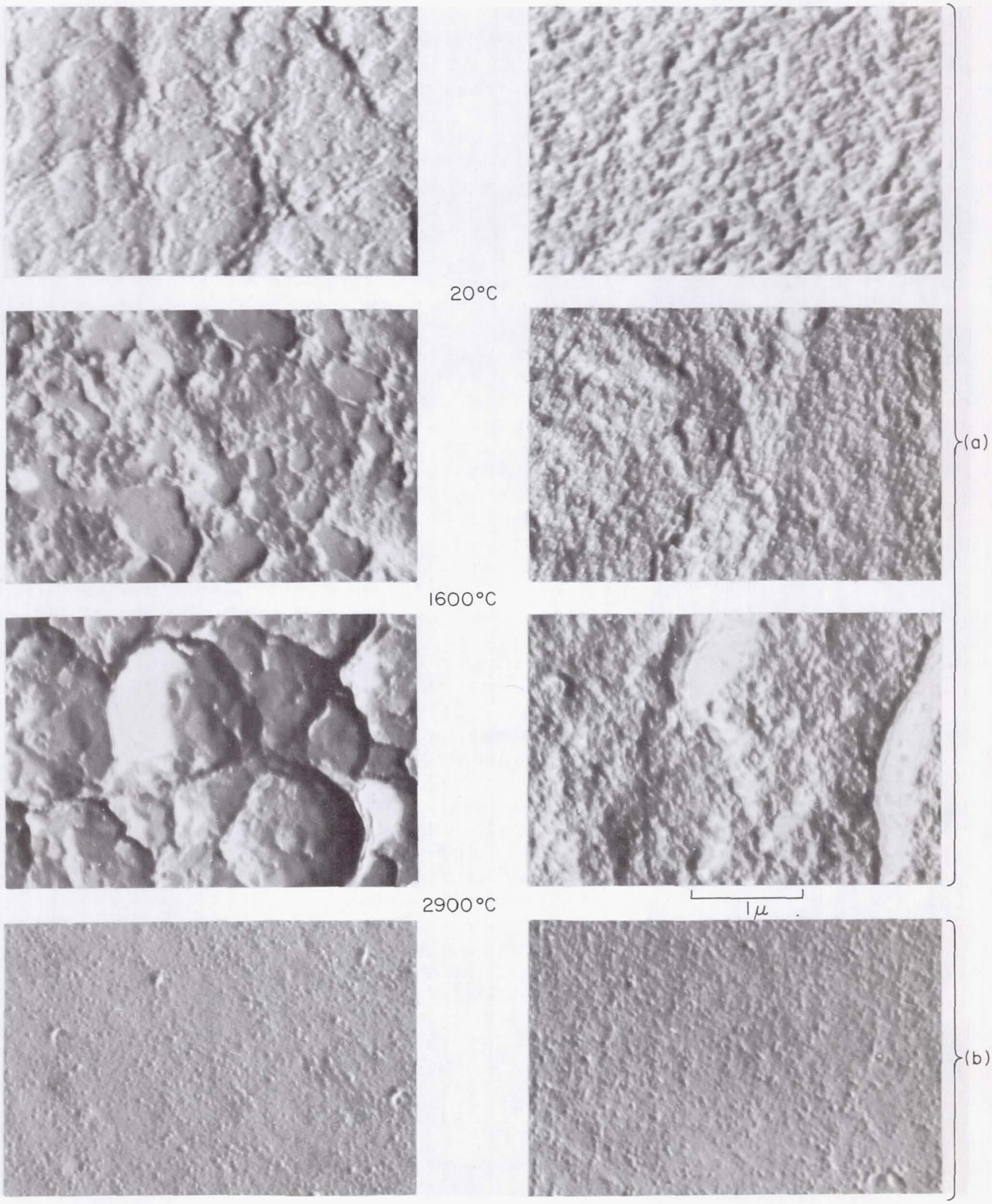


Fig. 6. Electron micrographs of two grades of glassy carbon
a) Fractured at various temperatures (fractographs)
b) Polished surfaces, as received

Initial studies (Ref. 5) were carried out using tensile specimens cut so that the stress axis made an angle of about 12 deg with the deposition plane. Results indicated that there was a well defined shear flow stress that increased with decreasing temperature, at least in the range 2200 to 2800°C. Flow stress values were also found to depend on the flatness of the basal slip surfaces, which varied with pretreatment and initial deformation temperature. The strain hardening rate was found to be low, but there was a definite increase in flow stress with strain rate.

The flattest basal planes (highest degree of preferred orientation) are obtained by annealing pyrolytic carbon at high temperatures under a compressive stress perpendicular to the deposition surface. This treatment could not be applied to the tensile-type specimen. In addition, certain features of this test configuration complicated interpretation of the results. A bending moment develops with elongation, there is a tensile stress component normal to the basal plane, and the small specimen dimensions and the weight of the load train resulted in a minimum applied shear stress of the order of 200 lb/in^2. Therefore, a modified grip and specimen configuration were developed to obtain pure shear deformation by the double shear technique (Ref. 6). This technique largely avoided the above mentioned difficulties, but the samples were found to be more susceptible to basal cleavage failure than the tensile-type specimens. In part, this is a result of the additional constraint placed on the deformation of the double shear specimen. Nevertheless, tests with the double shear technique confirmed the flow stress vs. temperature results obtained with the tensile configuration, as shown in Fig. 7. Surprisingly, compression-annealed specimens gave about the same flow stress values as 3000°C annealed-only specimens. There is some evidence that the compression annealing treatment used left appreciable internal stresses in the specimens and the microstructure of these specimens at test temperature may, therefore, have been similar to that of the annealed-only specimens. The increase of flow stress with strain rate was also confirmed.

At temperatures of 2700°C and above the flow stress values obtained with 3000°C annealed-only and compression annealed specimens were comparable with reported room temperature basal shear stress values for single crystals (60 to 70 lb/in^2). At lower temperatures, and with less severe pretreatments, much higher values were obtained. The pyrolytic samples used in the present studies are, of course, polycrystalline and the flow stress is evidently determined largely by the propagation of shear across tilt and twist boundaries. This is indicated by the decrease of flow stress with pretreatments that increase the average degree of preferred orientation. No quantitative information on the dependence of flow stress on preferred orientation in the slip region has been obtained yet, however. The temperature and strain rate dependence of the flow stress suggest that the propagation of slip across crystallite boundaries is a thermally activated process.

An oral paper on the basal shear studies was presented at the Seventh Biennial Conference on Carbon in Cleveland, Ohio, June 1965.

Microstructural Changes Accompanying Tensile Deformation of Pyrolytic Carbons Parallel to the Substrate

High-temperature tensile deformation of pyrolytic carbons parallel to the substrate proceeds in two stages. The first stage consists of the initial 10 to 15% elongation, while the second stage consists of higher elongations. To obtain further information on the deformation mechanisms involved, especially in the first stage, changes in optical microstructure and X-ray preferred orientation have been

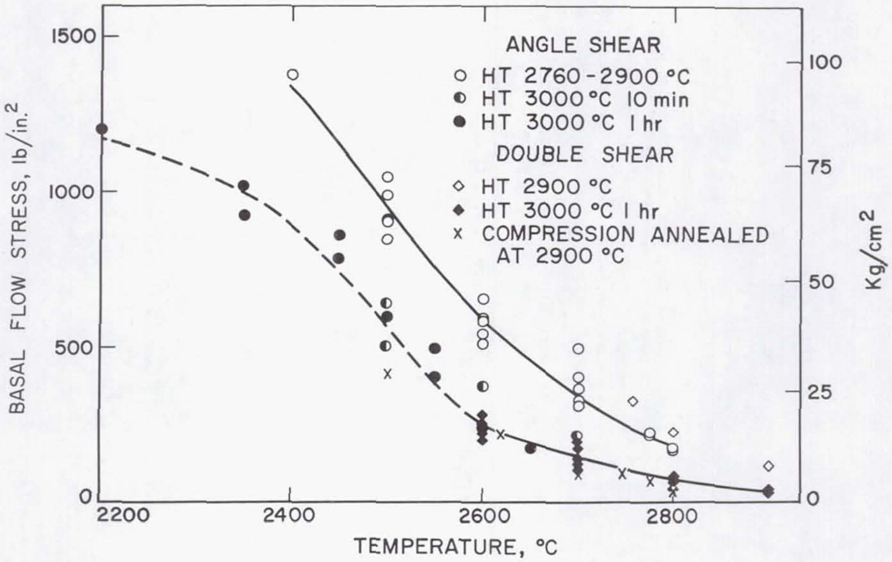


Fig. 7. Basal shear flow stress as a function of temperature for two types of shear specimen after various pretest treatments

observed as a function of tensile creep deformation in the range 2600 to 2800°C (Ref. 7).

The central portion of the gage section was examined in three orthogonal planes: basal edge cut parallel to the stress axis, basal edge cut perpendicular to the stress axis, and the basal (substrate) plane. Typical polarized light microstructures corresponding to three elongation values are shown in Fig. 8. The growth cone microstructure of as-deposited pyrolytic carbon is transversely isotropic and can be represented as a stack of hemispherically wrinkled sheets. Preferential dewrinkling of the structure parallel to the stress axis with increasing elongation is clearly evident in Fig. 8. After 10% elongation (end of first stage) the cone structure has completely disappeared parallel to the stress and on the basal plane, but is still visible perpendicular to the stress. After 21% elongation (second stage) the cone structure is absent in all three views. Magnetic susceptibility and preferred orientation measurements parallel and perpendicular to the stress axis also showed that wrinkles perpendicular to the stress had been removed preferentially by the deformation. After 10% elongation, the average basal plane orientation is within 2 deg of the stress axis, and the structure can be represented by a stack of corrugated sheets with the corrugations parallel to the stress. These observations are consistent with basal shear and dewrinkling as the deformation mechanisms operating during the first stage. It was also found that the same structure was produced by the same amount of deformation, regardless of temperature in the range 2600 to 2800°C. This was an assumption of the method used earlier to analyze creep strain vs. time data on pyrolytic carbons (Ref. 8).

An oral paper on the analysis of the creep results and the structural changes was presented at the Seventh Biennial Conference on Carbon in Cleveland, Ohio, June 1965.

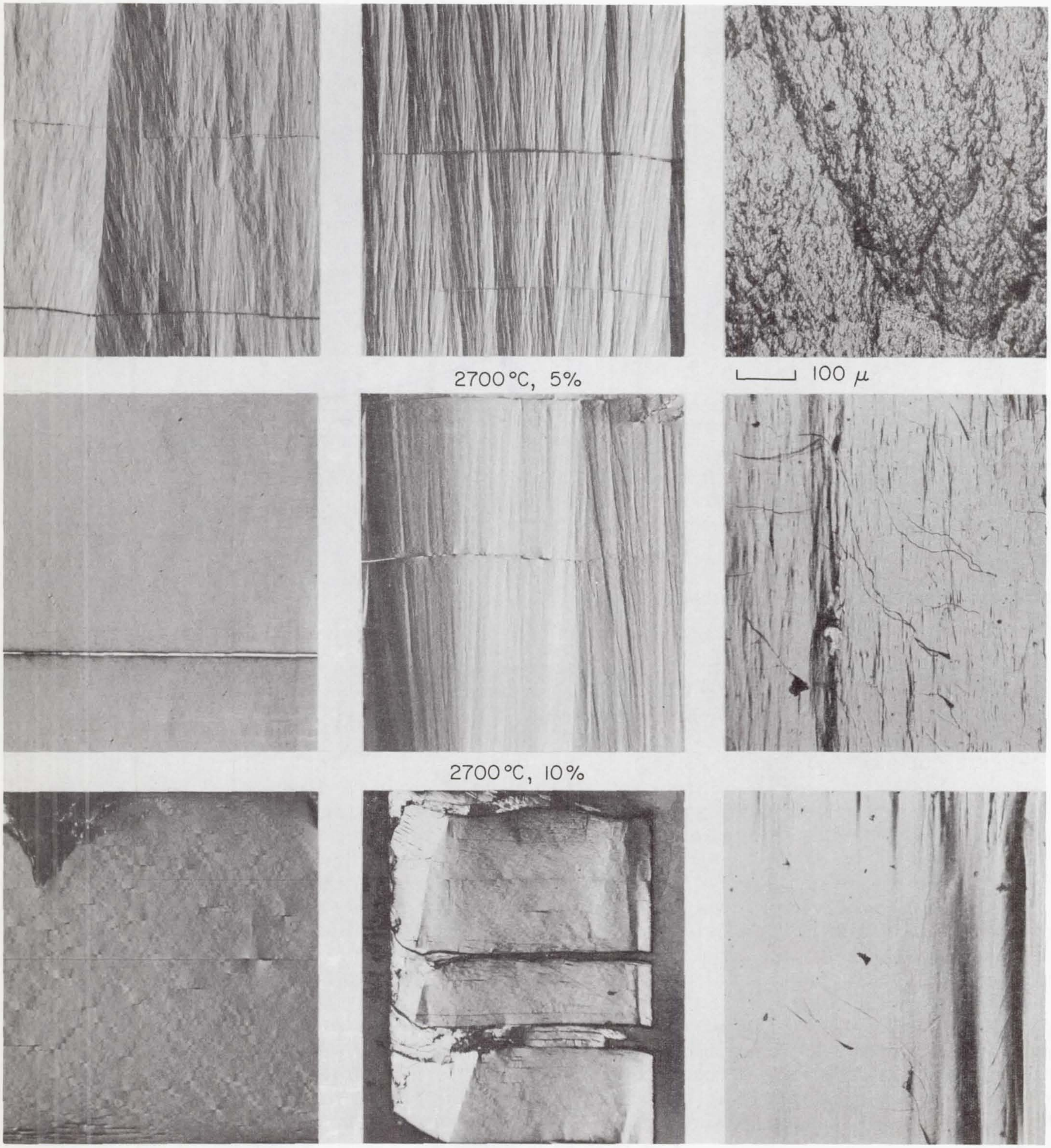


Fig. 8. Optical polarized light surfaces as a function of tensile elongation

Miscellaneous Activities

The apparatus and test procedures used for high-temperature tensile and creep testing are now being reviewed and a number of modifications have been made or are being studied to improve performance. A new graphite tube furnace with a 3000°C maximum temperature and a fast heat-cool cycle has been ordered. This furance will add flexibility to the present facilities for heat treatment and mechanical property investigations at high temperatures.

Three papers (Ref. 9, 10, 11) have been published in technical journals in the last 6 mo.

Contract No. 950112 with Barogenics, Inc. to develop an apparatus to melt carbon in an inert gas atmosphere under several hundred atmospheres pressure has been critically reviewed. This project was initiated with the minimum objective of obtaining for study graphite that had been passed through the liquid phase. It was hoped that eventually it might be possible to grow large single crystals. The engineering problems proved unexpectedly difficult and progress has been very slow. Interest in the properties of polycrystalline graphite solidified from the melt has declined and the prospects of obtaining single crystals superior in size and perfection to natural crystals appear quite remote with the present approach and the limited manpower availability. Therefore, it has been decided to terminate this project on completion of machining and pressure test certification of the pressure vessel. Every effort will be made to secure full documentation of the current (incomplete) engineering design. It is hoped to terminate the contract late in the first quarter of FY 1966.

Work Proposed

Continuation of the basal shear studies is planned with particular attention to the dependence of flow stress on microstructure. Methods will be sought to characterize the structure of the slip regions. A technical report on the basal shear work will be prepared. Limited additional studies on the structure of glassy carbon are planned and a technical report on the glassy carbon investigation, now in draft, will be completed. Technical reports on the analysis of pyrolytic carbon creep data and on the structural changes accompanying tensile deformation are also planned. Modifications of the high-temperature tensile and creep test facilities to improve performance will continue. Investigations on the mechanism of second stage deformation and failure in pyrolytic carbons will be started.

REFERENCES

1. Carniglia, S. C., "Grain Boundaries and Surface Influence on the Mechanical Behavior of Refractory Oxides - Experimental and Deductive Evidence." Conference on Ceramics, North Carolina State, Raleigh, N. C., November 16-18, 1964.

2. Kotlensky, W. V., "Tensile Properties of Glassy Carbon to 2900°C," Nature (to be published).

3. Fischbach, D. B., and Kotlensky, W. V., "Electron Micrography and Fractography of Glassy Carbons, Space Programs Summary 37-33, Vol. IV.

4. Fischbach, D. B., "Structure and Magnetic Properties of Glassy Carbon," Space Programs Summary, 37-32, Vol. IV.

5. Kotlensky, W. V., Fischbach, D. B., and Martens, H. E., "Basal Plane Shear Behavior of Pyrolytic Graphite at High Temperatures," Space Programs Summary 37-28, Vol. IV.

6. Kotlensky, W. V., "Basal Plane Shear in Pyrolytic Graphite," Space Programs Summary 37-31, Vol. IV.

7. Kotlensky, W. V., and Fischbach, D. B., "Structural Changes Accompanying Creep Deformation of Pyrolytic Carbon," Space Programs Summary 37-33, Vol. IV.

8. Kotlensky, W. V., "Analysis of High Temperature Creep in Pyrolytic Graphite," Space Programs Summary 37-30, Vol. IV.

9. Kotlensky, W. V., and Martens, H. E., "Structural and High Temperature Properties of Boron Pyrolytic Graphite," Carbon, Vol. 2, pp. 315-317 (1964).

10. Kotlensky, W. V., and Martens, H. E., "Structural Changes Accompanying Deformation in Pyrolytic Graphite," J. Am. Ceram. Soc., Vol. 18, pp. 135-138 (1965).

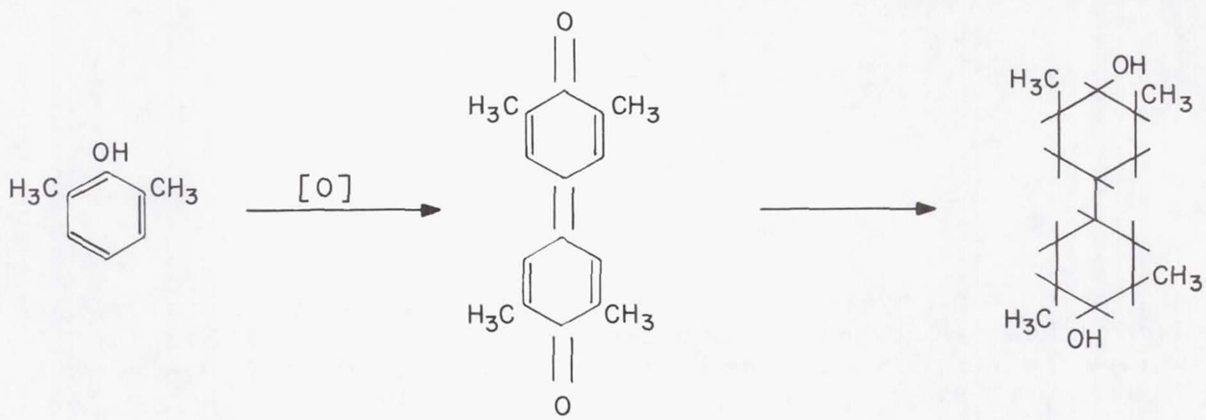
11. Kotlensky, W. V., "Deformation in Pyrolytic Graphite," Trans. Met. Soc. AIME, Vol. 233, pp. 830-833 (1965).

STABILITY OF POLYMERS AT HIGH TEMPERATURE
NASA Work Unit 129-03-11-02
JPL 329-30301-1-3820

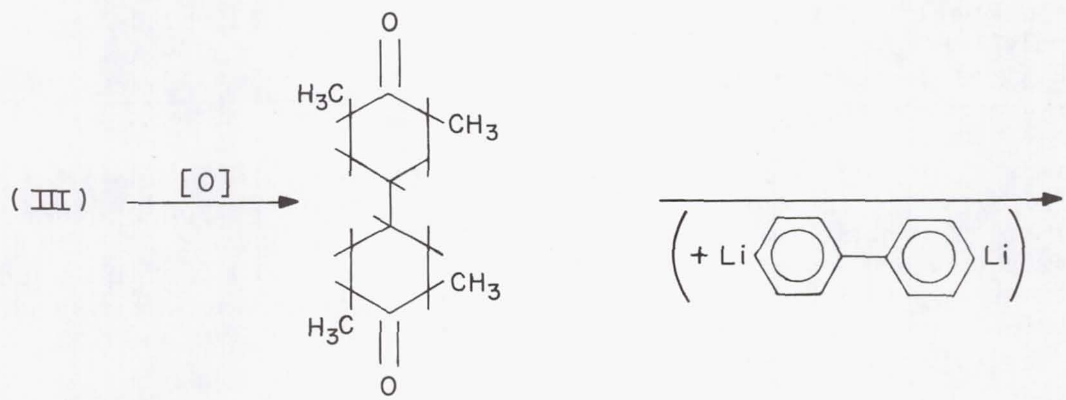
SUBSTITUTED POLY(BENZENES

The objective of these studies is to prepare tractable high-temperature polymers by known synthetic methods.

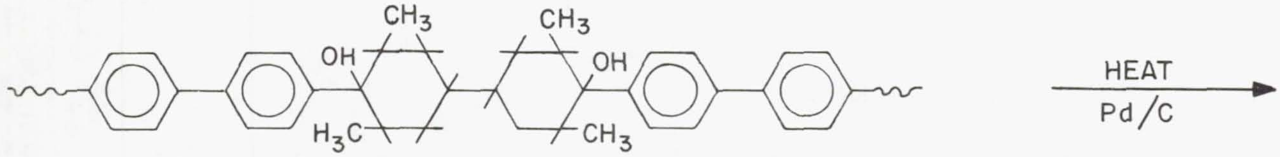
A series of poly(dimethyl benzenes) had been prepared previously by direct polymerization of the monomeric dimethyl benzenes. These were characterized for extent of ring vs. side-chain polymerization by infrared spectroscopy and molecular weights were determined by vapor pressure osmometry. They are more tractable than polyphenyls because they are soluble in solvents such as chloroform, benzene, and carbon tetrachloride, but are of low molecular weight (~600). Because of the low molecular weight and the need for polymers with more predictable structures, some new methods of synthesis are being studied. One that should give a poly (benzene-dimethyl benzene) is:



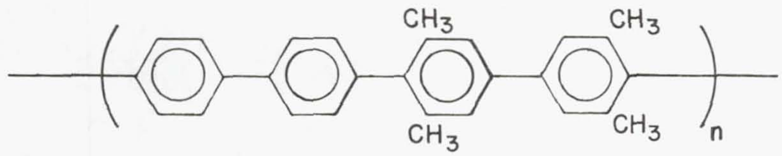
I II III



IV



V



VI

The 3, 3', 5, 5'-tetramethyldiphenoquinone (II) was prepared by oxidation of 2, 6-dimethylphenol (I). Then II was hydrogenated at 250°C and 1700 lb/in.^{2} for 10 hr to give the 3, 3', 5, 5'-tetramethylbicyclohexyl-4, 4'-diol (III), which analyzed 75. 58% cabron, 11. 85% hydrogen, compared with 75. 54% carbon, 11. 89% hydrogen, calculated for $C_{16} H_{30} O_2$. The reaction steps to give 3, 3', 5, 5'-tetramethylbicyclohexyl-4, 4'-dione (IV) and the polymer (VI) have not yet been carried out, although the reactions of aromatic ketones with lithio-phenyls has been previously made (Lawson, D. D. and Buess, C. M., J. Org. Chem., Vol. 25, p. 272, 1960). The product (VI) and poly(xylylene) will be subjected to structural analysis by Yen's method (Yen, T. F., and Erdman, J. G., ACS Petroleum Chemistry Preprints, March, 1962) to examine the applicability of this method to poly(aromatics).

As a means of removing chlorine that is apparently chemically bonded to polyphenyl prepared by ferric chloride catalysis and to convert the polyphenyl to a more tractable polymer, it has been hydrogenated at 300°C, 2000 lb/in.^{2} A very small yield (0. 2gm from 8gm of polyphenyl) of clear viscous oil that has an infrared spectra consistent with poly(cyclohexane) and is soluble in cyclohexane was obtained. Further hydrogenation experiments to increase the yield and obtain additional product for characterization are in progress.

ELECTRICAL PROPERTIES OF POLYMERS
NASA Work Unit 129-03-11-03
JPL 329-30401-1-3820

ELECTRON TRANSFER TO POLYACENAPHTHYLENE

The properties and reactions of polyacenaphthylene (PAcN)-sodium complex were found to exhibit different behavior from the previously investigated polymers (Ref. 1). PAcN undergoes very fast chain scission with formation of relatively large polymeric fragments as well as monomeric units. The presence of the former was found out by spectrophotometric measurements and of the latter by electron spin resonance techniques as well as by gas liquid chromatographic separation (Ref. 2).

The degradation of the polymer occurs even at very low temperature and depends mainly on the sodium concentration. At high sodium concentration it was possible to degrade PAcN of viscosity average molecular weight (M_V) of 10^6 to M_V of 20000 at -70°C within a matter of seconds. The rapid chain breaking rate correlates well with LCAO molecular orbital calculations (Ref. 1).

A mechanism of chain scission was proposed that accounts for all the experimental facts. The accumulated results lead to the conclusion that a relatively rapid charge transfer occurs in PAcN when electrons are transferred from alkali metals to this polymer. Further investigations of this equilibrium applied to mono and polysubstituted aromatic hydrocarbons is in progress.

CHARGE TRANSFER COMPLEXES OF SUBSTITUTED AROMATIC HYDROCARBONS WITH SODIUM

In the course of investigations of the formation and degradation of kinetics of vinyl aromatic polyradicalanions, a pronounced temperature effect was observed on the visible spectra of the poly (vinyl biphenyl) and poly (N-vinyl carbazole)-sodium complexes, as well as of the complexes of the corresponding ethyl substituted aromatic hydrocarbons dissolved in tetrahydrofuran THF (Ref. 2). This phenomenon was due to the occurrence of the following equilibrium:

$$Na + Ar \rightleftharpoons Na^+ + A\dot{\bar{r}} \qquad (1)$$

Where Ar and $A\dot{\bar{r}}$ represent a substituted aromatic hydrocarbon and its radical anion respectively. From a spectrophotometric study it was possible to determine the equilibrium constant of Eq. 1 for a number of systems over a wide temperature range.

These results offer a relatively simple method for the preparation of very finely divided sodium particles in a number of solvents, which may have extensive applications in organic and polymer chemistry.

CONDUCTIVITY

Previously, it was shown that the 1:1 PVCA-TCNE charge transfer complex exhibits semiconductor properties. Now measurements have been carried out over the complete composition range of the complex (Fig. 1), and a comparison was made with the properties of the complex of N-ethyl carbazole, ETCA, the monomeric compound having the structure of the polymer repeating unit. Also, modifications made on the Bridgman anvil apparatus for resistivity measurements allowed reliable determinations to be made of resistivities up to $10^{14}\,\Omega$-cm.

The new results showed that the PVCA-TCNE complex exhibits ohmic behavior for the complete composition range up to fields of about 8000 v/cm, and for all the pressures at which measurements were made, (i. e., up to 23, 000 atm).

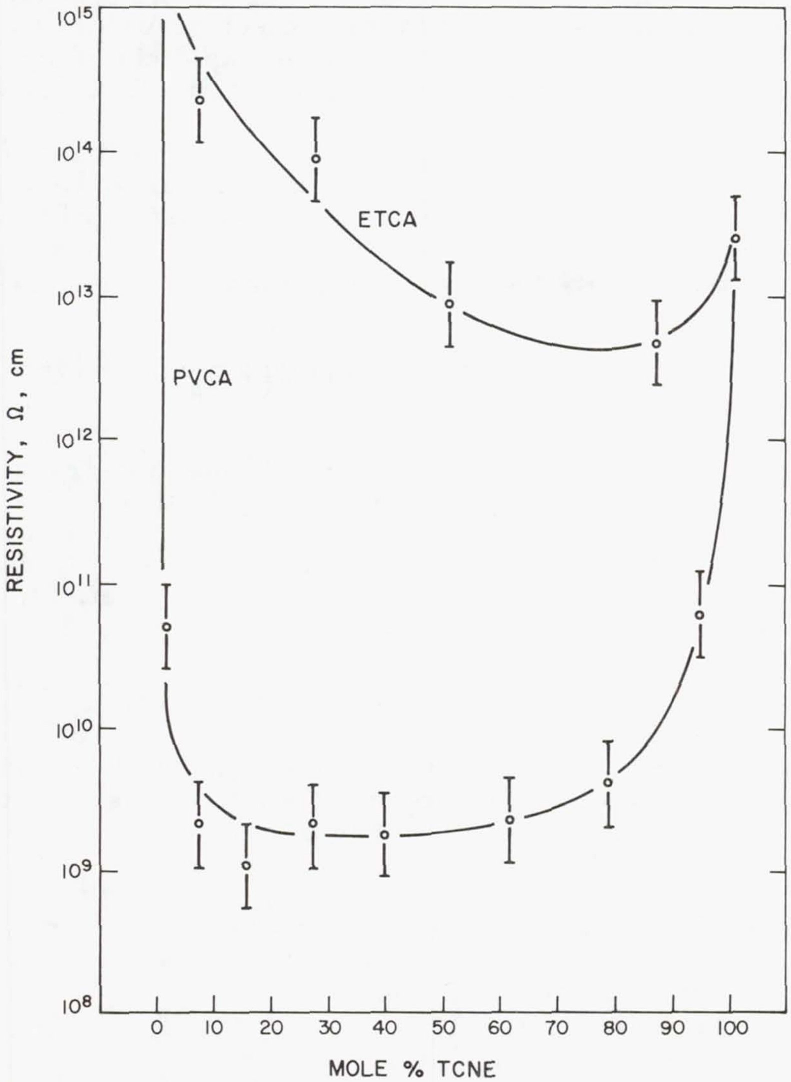


Fig. 1. Comparison of resistivity at room temperature and 15, 000 atm of poly (N-vinylcarbazole) (PVCA) and N-ethyl

Figure 1 shows the resistivity composition relationship at 15,000 atm. The resistivity of PVCA was above the range of the apparatus, i.e., 10^{14} Ω-cm, and the value 10^{13} to 10^{14} is in agreement with that reported in the literature.

The resistivity decreased by about four orders of magnitude with addition of only 1.5 mole % TCNE and addition of 10% results in a further decrease by a fraction of 15. Above 80 mole % TCNE, the resistivity rapidly increases. The relatively minor changes observed for intermediate concentrations may merely reflect comparable changes in complex concentration, or by inference in the number of charge carriers.

For comparison, results on the ETCA-TCNE complex are included in Fig. 1. Here, complexing does not seem to enhance conductivity significantly, suggesting that the polymer structure must offer some critical conditions to facilitate charge migration. Also, the maximum in the charge-transfer absorption bond (ca 580 mμ) exhibits a 20 mμ red shift in going from monomer to polymer, again suggesting greater charge delocalization for the polymer.

CHARACTERIZATION

Previous studies of solution properties indicated that the theta radius of gyration of PAcN (Space Programs Summaries 37-22) is comparable to that of polystyrene of equal degree of polymerization, a surprising result considering that one ought to expect greater chain stiffness for PAcN. To find out the applicability of the usual theories to this polymer, our studies were extended by using Zimm's light scattering method to determine the polymer theta dimensions directly.

Light scattering and viscosities were used along with Flory's relationship:

$$\left[\eta\right] = \Phi\left(\overline{h_\theta^2}\right)^{3/2}/M$$

to calculate the value of the nearly universal parameter Φ; $[\eta]_\theta$ is the theta intrinsic viscosity, $\overline{h_\theta^2}$ the unperturbed mean-square-end-to-end distance, and M molecular weight. By correcting the results for the effect of polydispersity, the calculated value of Φ was 2.1 to 2.3 x 10^{21}, which is in the correct range for linear flexible polymer coils. If the polymer were more rodlike, one would expect lower because of drainage effects. The value of $(\overline{h_\theta^2}/M)^{1/2}$ was about 600 x 10^{-11} and constant for the molecular weight range that was investigated (500,000 to 2,000,000).

To obtain a measure of the rotational potential about the backbone bond, we have compared our experimental value to that for free rotation. The appropriate free-rotation equation for a chain that consists of alternating bonds, one of which is free, is:

$$\overline{h_\theta^2} = 2Nl^2/(1 - \eta)$$

This equation yields the following expressions for the two possible stereoisomers for PAcN:

$$\overline{h_\theta^2} = \begin{cases} Nl^2 & \text{threo configuration} \\ 4Nl^2 & \text{erytho configuration} \end{cases}$$

which lead to theta-to-free-rotation ratios for the end-to-end distance of 3.3 and 1.65 for threo and erythro, respectively.

One cannot decide (on the basis of the available results) which of the isomers is more likely, although steric considerations favor erythro. We plan to attempt to resolve this question by examining rotational potentials that agree better with the experimental results.

PUBLICATIONS

Contributions have been made to Space Programs Summaries 37-31, 37-32, and 37-34.

REFERENCES

1. Rembaum, A., and Moacanin, J., "Electron Transfer to Vinylaromatic Polymers," Symposium on Exchange Reactions IAEA Brookhaven National Laboratory, May 31 - June 4, 1965.

2. Rembaum, A., Eisenberg, A., and Haack, R., J. Am. Chem. Soc., Vol. 87, p. 2291 (1965).

RHEOLOGICAL PROPERTIES OF POLYMERS
NASA Work Unit 129-03-11-04
JPL 329-30501-1-3820

GLASS TRANSITION AND VISCOELASTIC PROPERTIES

Because of the commercial development of ionomers, considerable interest in the mechanical properties of polymers containing polar groups is to be anticipated. In contrast to these polymers (which are normally rigid), the combination poly (propylene oxide)-lithium perchlorate yields a viscoelastic system whose properties vary greatly with composition.

In general, when lithium perchlorate is dissolved in ethers, volume contractions are observed that are caused by strong interaction forces between the field of Li^+ and polarizable ether oxygens. The effect of these forces on the viscoelastic properties of both low (commercial PPG 2025) and high molecular weight, poly (propylene oxide), containing varying amounts of dissolved lithium perchlorate (LP) was investigated by means of dilatometric, modulus, and damping constant measurements over a temperature range between -80 and 80°C.

The glass transition temperature, T_g, for PPG 2025 was raised from -70°C to 40°C for 25 wt % LP. Neither modulus nor damping curves could be superposed on the reduced $T-T_g$ temperature scale. Below 15 wt % LP the various properties could be interpreted as resulting from the superposition of the behavior of free polyether segments with that of segments nearest neighbors to LP. Above 15 wt % LP, no free segments are left.

The behavior of the high molecular weight polyether was similar, except that below 15 wt % LP the single T_g observed for PPG 2025 was split in two transitions, T_g for the polyether at -65°C, and another at -10°C. The latter is believed to be a transition for polyether helixes stabilized by LP situated in the helix core.

This work has been reported in Space Programs Summaries 37-31 and 37-34, and will be presented at the American Chemical Society meeting in September 1965 at Atlantic City.

The following additional studies are planned: viscosity, stress relaxation, and possibly dielectric dispersion. The torsional pendulum is being modified to extend its temperature range down to liquid nitrogen.

Studies on vinylaromatic polymers have been postponed pending the award of a contract for the synthesis of these polymers.

PURIFICATION OF CARBOXYL-TERMINATED POLY (ALKYLENE OXIDES) (PAO)

Improvements have been made in the methods of obtaining pure dicarboxylated PAO. Purified materials still show presence of hydroxyl groups (15%) thought to have their origin in monocarboxylic PAO. The effectiveness of two triepoxides and one imine as curing agents for PAO-COOH have been determined. The catalysis of the systems PAO-COOH - epoxide and PAO-COOH - imine have been studied in preliminary experiments.

A comparative study of the properties of cured carboxyl terminated poly (butadienes) and carboxyl terminated poly (propylene oxides), using preparations with similar carboxyl and nonfunctional material content, will be made. Other epoxides and imines will be investigated as curing agents. The effect of tertiary amine, organometallic, and other types of catalysts on cure rates and on physical properties at ambient and elevated temperatures will be studied.

ORGANIC CHEMISTRY
NASA Work Unit 129-03-11-06
JPL 329-31501-1-3260

Major emphasis has been on the development and application of nuclear magnetic resonance (NMR) techniques for quantitative and qualitative analyses of mixtures, study of molecular electronic structures, study of molecular energy transfer and rate processes, and on space science experiments. Other work has involved synthesis of epoxides for NMR and polymerization studies and synthesis of certain other model compounds for NMR studies.

ACTIVITIES DURING REPORT PERIOD

Contribution to the Space Programs Summaries; Presentation and Publications

1. "Relative Signs of the Nuclear Spin Coupling Constants in Propylene Oxide and Indene Oxide," J. Chem. Phys., Vol. 42, 650 (1965).

2. "The Relative Signs of the NMR Proton-Proton Coupling Constants in Styrene Sulfide and Styrene Imine," J. Am. Chem. Soc., Vol. 87, 220 (1965).

3. "Analyses of the NMR Spectra of the Vinyl Protons of Cyclopentadiene and Cyclohexadiene Using Spin Decoupling," prepared and submitted for presentation at September National American Chemical Society Meeting at Atlantic City.

4. "The Use of the ^{19}F NMR Spectra of Trifluoroacetyl Groups in the Characterization of Alcohols, Poly (Propylene Oxides), and Other Organic Functionalties," prepared and submitted for presentation at September National American Chemical Society Meeting at Atlantic City.

5. "Nitrogen Analogues of Sesquifulvalene. II. Theoretical Correlation of Ground State Properties," accepted for publication in J. Am. Chem. Soc.

6. "Nitrogen Analogues of Sesquifulvalene. III. Theoretical Correlation of Excited State Properties," accepted for publication in J. Am. Chem. Soc.

7. "Internal Field-lock Systems," invited talk presented at 6th Conference on Experimental Aspects of NMR, Mellon Institute, Pittsburgh, Pennsylvania, February 28, 1965.

8. "NMR of Phosphorous Compounds. II. The Relative Signs of the Spin-Spin Couplings in Dimethylphosphine and Methylphosphine," manuscript completed and illustrations in preparation.

9. "Molecular Orbital Calculation. I. Some Cyclobutadiene Systems Joined with Two Cyclopropenyl, Cyclopentadienyl, or Cycloheptatrienyl Rings," manuscript completed and paper ready to be submitted.

10. "Molecular Orbital Calculation. II. Treatment of 1, 3, -π-Interaction in Cyclobuturyl Systems," manuscript completed and illustration in preparation.

11. "The ^{19}F NMR Spectra of the Trifluoroacetates of Poly (Alkylene Oxide)," Space Programs Summary 37-33, Vol. IV.

12. "On the Correlation of Geminal and Vicinal Nuclear Magnetic Resonance Spin-Spin Coupling Constants with Substituent Electronegativities," Space Programs Summary 37-33, Vol. IV.

Analytical Chemical Applications

1. Continued NMR studies of nature and quantitative analyses of hydroxyl groups in the solid propellant additive alrosperse.
2. Continued NMR analyses on elastomer and potting compounds from Surveyor program.
3. Provide qualitative analytical data on methylhydrazine fuel mixtures.

Instrumentation

1. Received Varian time-average integrator, which is being tested with A-60 NMR system.
2. Discovered possibility and developed device for using a sample external to a NMR receiver coil to control a NMR spectrometer. With this device recorded first field-lock spectra of ^{14}N ^{13}C ^{11}B and ^{3}P nuclei. The patent possibilities for this device are being explored.
3. Built a linear sweep unit for HR field-lock NMR spectrometer using frequency to voltage conversion and an X-Y recorder.
4. Overhauled A-60 NMR spectrometer receiver and recorder circuits.
5. Carried out feasibility study of the design of a wide-line NMR spectrometer for a Voyager experiment or lunar soft-landing experiment, which indicates that NMR techniques could conveniently analyze for water in lunar and Martian soil and rock sample plus provide data on the seasonal variation of moisture in Martian soil and atmosphere.

High-Resolution NMR Problems

1. Discovered that the ^{14}N spectra of a number of isonitriles have extremely narrow resonance lines.
2. Discovered that the ^{19}F NMR spectra of trifluoroacetates provides an excellent classification scheme for hydroxyl compounds.
3. Continued ^{19}F NMR studies of derivatives of poly (propylene oxide) from which a scheme has emerged that can be used to determine sterochemistry of the chains in the polymers.

4. In collaboration with Professor J. D. Roberts and Dr. D. Clark on the Caltech Campus recorded ^{19}F spectra of certain ^{15}N containing aromatic compounds, which revealed first observed long-range ^{19}F-C-C-C-C-^{15}N spin-spin coupling.

5. Several research associates of Professor J. D. Roberts on the Caltech Campus used our A-60 spectrometer for a number of high-resolution and temperature NMR studies.

6. Started a study of the very complicated ^{19}F and ^{1}H NMR spectra of 1,1-difluoro-2-methylbutadiene.

Organic Chemistry

1. Synthesized large quantities of CHF_2CHBr and CHFBrCHBr. From the latter prepared CHF-CHBr. These compounds are precursors in the syntheses of the isomeric 1,4-difluorobutadiene for NMR and physical studies.

2. Prepared and purified a number of trifluoroacetates of various alcohols for NMR studies.

3. Attempted unsuccessfully several times to prepare ethoxyethylene oxide by reaction of ethylvinylether and m-chloroperbenzoic acid.

4. Started synthesis of vinylcyclopropane for NMR studies and as a precursor for the synthesis of cyclopropyl ethylene oxide.

5. Synthesized trimethylsilanoethylene oxide for NMR and polymerization studies.

6. After several attempts, prepared sample of triethylphosphine as a precursor to syntheses of triethylphosphine oxide and tetraethylphosphonium salts for NMR studies.

FUTURE ACTIVITIES PLANNED

1. Finish manuscripts now being written and start several new ones.

2. Continue analytical support work, studies of high-resolution NMR spectra of small molecules, studies of the use of the ^{19}F NMR spectra of the trifluoroacetyl group in the classification of organic functional groups; prepare several new epoxides for NMR and polymerization studies, of NMR as a possible soft-landing experiment for the analyses of soil, rocks, and the atmosphere of Mars; continue syntheses of certain organic molecules for NMR studies, maintenance of NMR spectrometers, and the use of time averaging techniques.

3. Expect to invest considerable time in moving all equipment into new building soon.

4. Should receive Varian A-56/60 spectrometer to replace present Varian A-60 that we now have. Problems associated with the installation of this new and improved spectrometer must be considered.

5. Planning trip to Shell Development Corporation to perform 100 M_6 proton experiments that we cannot do with our present spectrometers.

ANALYTICAL CHEMISTRY
NASA Work Unit 129-03-15-02
JPL 329-30801-1-3260

For a number of years now, a major portion of the Analytical Chemistry effort has been troubleshooting problems connected with the Laboratory space program. This effort is broad in scope and encompasses materials, processes, hardware, and electronic components.

Polymeric materials used in spacecraft were evaluated for outgassing characteristics, and the nature of the evolved products determined. These products often are quite damaging to electronics, metals, etc. Polymerics investigated included insulations, coatings, cements and potting compounds.

Some attempt has been made to anticipate problem areas, but not much could be accomplished because of the demands for immediate solutions to numerous emergency problems. The attached memorandum covers a joint effort to solve some of the problems associated with the potting of electronic components.

As might be expected, electronic component failures are a constant problem. Some of these failures are due to poor workmanship, faulty design, or poor choice of materials. Occasionally, the failures are induced by unrealistic tests applied to finished electronic devices.

We have established the failure mode for a wire-wound resistor. The coatings were suspected of being faulty and therefore penetrated by corrosive contaminants which later induced failure both in use and in storage. The coating was found to be quite impervious, and failures were due to the polyvinyl chloride labels applied to screened resistors just prior to so-called burn-in, a part of the screening test. The resistors under the heavy load became hot, the labels decomposed yielding hydrochloric acid as one of the decomposition products. Hydrochloric acid rapidly depolymerized the silicone coating exposing the wire to corrosion as well as electrolysis under applied load, leading to frequent failure both in use and in storage.

Our work on hardware included such items as thermal compensators used in a resonating cavity[1], and the valves and welded lines on the attitude control system. The cause of malfunction in the thermal conpensators was determined and rectified. One of the problems connected with the attitude control system was considerable oxidation of the stainless lines during inert gas welding. This difficulty was overcome by certain changes in procedure as well as the use of a simple tester to establish when air or water are essentially absent in the argon gas passing through the stainless lines prior to welding.

One of the more successful in-flight experiments on the Mariner was the magnetometer. It was discovered rather late in the scheduled delivery of the magnetometer from the vendor that both the helium lamps and the cells were unreliable, having a life of only 100 hr or less. The Analytical Group had a considerable hand in developing and actually making the flight helium lamp and cell. More work is being done in the effort to maximize the performance of these items by studying the effect of such parameters as geometry and helium pressure used to fill them.

---

[1] Mariner IV.

Our more current concern has been problems associated with the Surveyor program. Helium used to pressurize the fuel tank penetrates the bladder, dissolves in it and then causes uneven thrust from the guidance motors used in conjunction with the solid retro-motor. We have been studying both the helium permeation through the bladder and extent of its solubility in the fuel.

In the future our efforts along the lines described above will be curbed by a personnel decrease and the firm commitment of some others to a flight development program.

EMBEDDING AND ENCAPSULATING COMPOUNDS

Clear embedding or encapsulating compounds which will satisfy various modes of packaging and also adequately meet the demands of space applications[2] are either commercially available or can be developed from existing basic polymeric materials.

Although fillers reduce the internal stresses in a cured resin, unfilled, clear systems with very low internal pressures can be formulated, and thus the advantages of clarity can be put into use.

The phenomenon of birefringence can be utilized to examine the stressed state and estimate the magnitude of stress.

---

[2] Effect of radiation has not been considered.

SOLID STATE MATERIALS
NASA Work Unit 129-03-15-04
JPL 329-31001-1-3510

The objective of this work is to obtain information which will lead to a better understanding of the laws and fundamental mechanisms governing the mechanical, electromagnetic and electronic behavior of solids, so that more effective use can be made of materials for structural and electronic applications.

SODIUM CHLORIDE CRYSTALS

The growth and testing of NaCl crystal rods, which is the major effort in this task, had to be discontinued at the end of the second quarter due to the loss of personnel. At the beginning of the fourth quarter new personnel were hired and the process of training has been carried on. The data obtained during the bend testing of the crystal rods and the purchased cleavages have been analyzed and prepared as a progress report entitled Effect of Predeformation on the Mechanical Properties of Sodium Chloride Crystals, which is in the final stages of editing.

The crystal growing equipment has been modified to allow one unit to operate under high vacuum conditions. The other unit which confines the molten salt in a quartz tube has been modified to provide better viewing of the liquid surface and a more uniform temperature region. The crucible temperature control loop requires some additional improvement. These modifications should permit the growing of single crystal rods of higher purity and with lower dislocation densities.

Impurity levels which are normally considered as negligible may be of major importance in this activity. It has been noted that the molten sodium chloride reacted with the silica crucible; this was attributed to the presence of OH^-. Pretreatment of the liquid NaCl with dry HCl has been found to eliminate this reaction. A contract has been let for the production of premelted crucible charges of sodium chloride treated with HCl and Cl_2 to remove OH^- and all other likely anionic impurities. Removal of metallic impurities, notably calcium, is also being pursued. Potential vendors are being evaluated prior to the awarding of a contract for purification of additional material. Commercial analytical techniques for the determination of low level of impurities has been determined to be unsatisfactory. Repeated analysis of the same samples for calcium in NaCl gave a reproducibility of no better than ±8 parts/million. A new ultrasensitive technique developed by Dr. P. Geiger of JPL will be tried.

The major efforts in the future will be directed toward the growth of uniform crystal rods of NaCl from highly purified materials using the newly modified equipment and recently developed techniques. The effects of impurity content on dislocation density and mechanical behavior will be studied. It has been predicted on the basis of previous results that ultra high purity crystal rods should show a yield shear stress of 33 g/mm^2 and should have negligible work hardening during the first stage of plastic deformation.

TAYLOR WIRES

The major effect in this task is the determination of the cause of the ultrahigh strength of shiskers by the determination of the effect of size on the strength of perfect and imperfect filamentary crystals. To do so, it has been decided to develop materials and techniques for producing filamentary crystals by the Taylor wire method.

The machine which was originally constructed for this drawing operation has been modified to correct many of the operational difficulties which were experienced. The feed mechanism is now connected to the drive motor by a multiratio gear reducer, thus giving a greater range and higher precision. This modification also makes it possible to change the diameter of the drawn filament while the machine is in operation. The filament is now drawn by a pair of rubber rollers instead of a revolving drum. This will facilitate the drawing of undeformed filaments with cores larger than 25μ. The feed and rollers are synchronized by direct mechanical coupling. Possible drawing speeds range from 15000 to 7.5 in. per min.

One cause for the discontinuities in the drawn filaments was thought to be due to gas dissolved in the metal. It was therefore decided to vacuum-melt and recast the metal prior to the drawing operations. Numerous difficulties were encountered in attempting to do this and only marginal success at elimination of the discontinuities was realized.

Deformation and fracture of the metal filaments also occur as a result of the differential thermal contraction as the composite filament cools to room temperature. A glass with a coefficient of thermal expansion matching that of copper has been obtained. Attempts will be made to draw composite filaments in which the high-expansion low-melting glass will act as a liner between the metal and the outer shell.

The major efforts in the future will be directed toward use of the modified equipment and newly developed techniques in various combinations so as to produce reproducible, continuous filaments.

THERMOELECTRIC POWER IN COPPER BASED ALLOYS

The computer program for analyzing changes in phon drag thermopower with alloying has been completed and applied to the data on Cu-Al and Cu-Si alloys. Numerical analysis indicates, that for 0.77 atomic % Al in Cu, phonon scattering occurs mainly through the mechanism of mass difference while for 1.1 atomic % Si in Cu, phonon scattering occurs by means of equal contributions from mass difference and lattice distortion due to the solute atom. The following publications have resulted from the above-mentioned work:

1. Weinberg, Irving, Phonon Drag Thermopower in Cu-Al and Cu-Si Alloys, NASA Technical Report 32-730, May 1, 1965.

2. Weinberg, I., Phonon Drag Thermopower in Cu-Al and Cu-Si Alloys, accepted for publication in Physical Review. Abstract in Physical Review Letters, 14 (22) May 31, 1965.

3. Weinberg, I., and Schultz, C. W., Thermoelectric Power in Cu-Al and Cu-Si Alloys, paper delivered orally to American Physical Society. Abstract in Bulletin of the American Physical Society 10, 325 (1965).

Consultation and discussions with the group in Guidance and Control Research who are working on advanced sensors which utilize the thermoelectric effect have continued and have assisted in the setting up of proper advanced development experiments.

Future efforts will be directed toward procurement and testing of suitable high-purity well annealed Cu-Ag and Cu-Au alloys as a continuation of the work on Cu-Al and Cu-Si. Additional alloys will be selected, procured, and tested as part of a sustained program to determine and understand the sources of phonon scattering in dilute alloys. Cooperation and consultation with the guidance and control group will continue with respect to device applications.

THERMOELECTRIC POWER IN NIOBIUM-ZIRCONIUM ALLOYS

Measurements of the thermoelectric power in niobium and niobium-zirconium alloys has been completed over the temperature range from 10 to 330°K. Measurements were performed on niobium and niobium alloyed with 1, 1.8 and 3.8 atomic % zirconium respectively. These alloys represent an advanced electronic material in which addition of Zr to Nb in the amounts mentioned above increase the superconducting transition temperature. A sizeable positive phonon drag component is observed in niobium. Addition of zirconium partially quenches the phonon drag component and introduces a negative peak at $T \approx 15°K$. The results are currently under analysis, in an attempt to gain some understanding of the relatively unknown transport properties in these technically important alloys.

Analysis of the recorded data will continue, and consideration will be given to extending this work to higher concentration alloys and higher temperature.

SUPERCONDUCTING TUNNELING EFFECT

Modification of a currently existing vacuum system has been completed and superconductor-oxide-superconductor junctions fabricated using lead as the superconducting material. Voltage-current characteristics at 4.2°K have been determined for a number of junctions and the Josephson tunnelling effect observed. Reproducibility and durability of the junctions present a major problem hence considerable effort has been directed toward a solution of this problem.

Future efforts will be concentrated toward obtaining better control of film and junction thickness. Thought will be directed toward utilization of these devices in the overall JPL effort.

CARBONS AND GRAPHITE

The program for FY 1965 included investigations on the structure sensitivity of the magnetic susceptibility and other electronic properties of various carbons and continued studies on the kinetics and mechanism of the graphitization process. Progress in all of these areas was noted in the first two quarterly reports. Activities during the second half of the year included studies of the peak displacement method of measuring the apparent crystallite diameter, the magnetic susceptibility and X-ray structure of glassy and pyrolytic carbons, the effect of high-temperature plastic deformation on graphitization, and the significance of the high effective activation energy observed for graphitization.

Apparent Crystallite Diameter Measurement Techniques

The apparent crystallite diameter, L_a, is an important structural parameter in the graphitization and electronic behavior of carbons. The best method of determining L_a, by Fourier analysis of the profile of a (hkO) diffraction peak, is difficult and tedious. Two simpler methods have been investigated. For disordered carbons, the peak intensity positions of the (hk) diffraction maxima are shifted to higher angles in inverse proportion to L_a. Although approximate, this method can be applied to visual reading of Debye-Scherrer films. Peak displacement measurements using the (10) and (11) peaks indicate that this method gives good results for $L_a \leq 100$A, as found in glassy carbons. For larger L_a values, as encountered in pyrolytic carbons, the probable error becomes quite large but good order-of-magnitude estimates are easily obtained. Magnetic susceptibility measurements offer a more promising technique for as-deposited pyrolytic carbons, as shown in Fig. 1 (Ref. 1-3). The L_a values for the pyrolytics were determined by the peak profile method (Ref. 3). The magnetic susceptibility also depends strongly on layer ordering and the dotted arrows on some of the data points indicate corrections to a constant value of layer stacking order corresponding to a unit cell height of 6.85A. However, with adequate "calibration" data, magnetic susceptibility measurements in combination with X-ray unit cell height measurements could provide a simple and useful alternative method for determining L_a.

Structure Sensitivity of the Magnetic Susceptibility

The structure dependence of the diamagnetic susceptibility is also of interest in understanding the electronic behavior of carbons. The increase in total susceptibility $_T$ with L_a, shown in Fig. 1, is well known from studies on conventional synthetic carbons (such as pitch-coke) for $L_a < 200$A. It may reflect the transition from molecular to solid state band electronic behavior. However, the continued increase of χ_T with $L_a > 200$A has not previously been observed because it is obscured by increasing layer ordering in conventional carbons. It may result from limitation of electron orbit diameters by crystallite boundaries. In combination with the layer ordering dependence, the L_a dependence above 200A provides an explanation for the susceptibility minimum which occurs as a function of heat treatment in pyrolytic carbons. Some data for a nongraphitizing carbon, glassy carbon, are also shown in Fig. 1. L_a was measured by the peak-displacement method. The initial rise of χ_T

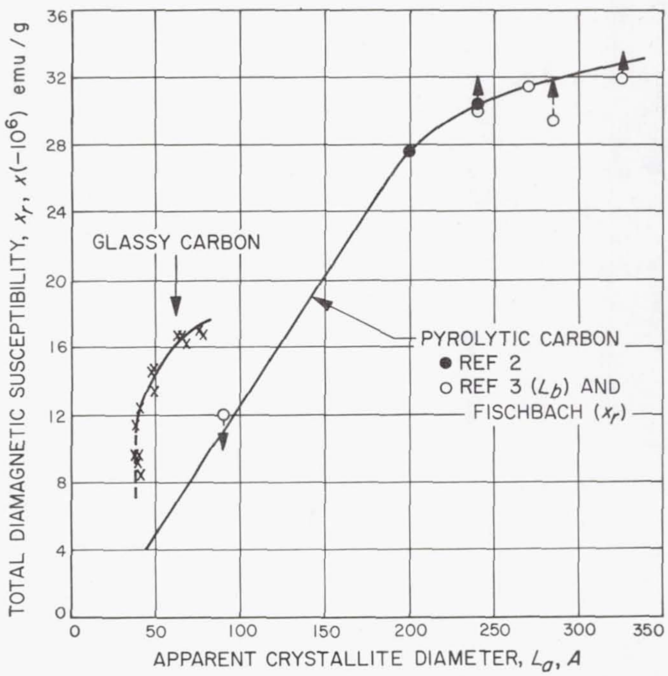


Fig. 1. The dependence of the total diamagnetic susceptibility on apparent crystallite diameter for turbostratic pyrolytic carbons and glassy carbon

with L_a is much more rapid for this carbon. Good agreement with published data on cellulose carbon indicates this may be a characteristic feature of nongraphitizing carbons, but the significance of this behavior is not yet understood.

Effect of Deformation on Graphitization

Kinetic studies have shown that graphitization depends sensitively on microstructural parameters such as L_a and preferred orientation. It has also been well established that high temperature plastic deformation produces extensive and accelerated microstructural changes. Deformation may therefore be expected to influence graphitization. This has been investigated by comparing the X-ray structural parameters of the gage (deformed) and butt (undeformed) portions of pyrolytic carbon tensile creep specimens deformed in the range 2600 - 2800°C. In all cases where the elongation exceeded 5% the deformed material had lower unit cell height (more layer stacking order) and larger L_a than the undeformed material. This difference could also result from a temperature gradient in the creep furnace (butt ends cooler than gage section). Further tests are underway to check on this possibility.

Mass Transport and Diffusion in Graphite

The effective activation energy, ΔH, for graphitization is about 260 kcal/mole and creep of pyrolytic carbon appears to be governed by a similar ΔH value. The accepted ΔH value for self-diffusion parallel to the layer planes is only 163 kcal/mole.

Lack of detailed knowledge about fundamental thermally activated processes in graphite has prevented understanding these results, but it now seems possible to at least rationalize the different activation energies for these processes. Theory suggests that direct interchange should be the lowest energy mechanism for self-diffusion. However, processes like graphitization and creep probably require mass transport which can only be provided by mechanisms like vacancy or interstitial diffusion. Recent theoretical and experimental developments reported in the literature indicate that 260 kcal/mole is a reasonable activation energy for layer plane diffusion by a vacancy mechanism. The possibility that c-axis diffusion is important in creep and graphitization cannot be ruled out, but this should also have a high activation energy.

Miscellaneous Activities

An automatic recording electromagnetic microbalance has been purchased. This will extend the magnetic susceptibility measuring capability to smaller sample sizes and make possible temperature dependence studies (with addition of a vacuum system and dewar). A note on application of the diamagnetic properties of pyrolytic carbons to measurement of high magnetic field strengths was published (Ref. 5). Oral papers on the kinetics of graphitization and the structure-sensitivity of the diamagnetism of pyrolytic carbons were presented at the Seventh Biennial Conference on Carbon, Cleveland, June 1965. Two reports on the kinetics of graphitization of pyrolytic and conventional carbons are in preparation.

Proposed Research

In FY 1966 this work will be combined with the other research on carbon and graphite into a single task. Studies on the kinetics and mechanism of graphitization will be continued with emphasis on the effects of microstructure, plastic deformation and heat treatment technique. The new balance will be put into operation. Studies on preferred orientation and magnetic susceptibility anisotropy of pyrolytic carbons are planned to determine if both principal susceptibilities, χ_c and χ_a, are structure sensitive.

REFERENCES

1. Fischbach, D. B., "Kinetics of Graphitization," SPS 37-31, Vol. IV, pp. 103-5.

2. Poquet, Elisabeth, "Structure et Propriétés Diamagnétique des Pyrocarbones," Journal de Chimie Physique 60, 566 (1963).

3. Guentert, O. J., "X-ray Study of Pyrolytic Graphites," Journal of Chemical Physics 37, 884 (1962).

4. Fischbach, D. B., "Structure and Magnetic Properties of Glassy Carbons," SPS 37-32, Vol. IV.

5. Fischbach, D. B., "Comments on 'Diamagnetic Gaussmeter,'" Rev. Sci. Instr. 36, 241-3 (1965).

INORGANIC CHEMISTRY
NASA Work Unit 129-03-15-06
JPL 329-31401-1-3260

PROGRESS AND STATUS

Since January 1, 1965, several attempts have been made to deposit a niobium film directly on copper by means of the pyrolysis of trimethyl-dichloroniobium. Small copper cylinders were heated to 700°C in vacuum, and the trimethyldichloroniobium was admitted at low pressure. The apparatus and procedures were virtually identical with those used in the previously described work involving niobium film deposition on gold foil. The dimensions of the copper cylinder were chosen to fit the existing apparatus for superconductivity measurement. Although the results of the plating experiments were not wholly discouraging, films of sufficient uniformity to permit superconductivity measurements were not obtained.

Laboratory work on the search for other new compounds of the transition metals was not completed because the cognizant scientist was transferred and the laboratory closed on April 27, 1965.

SUMMARY OF RESULTS

No major procurements occurred during this report period.

As this is the final report on this work unit, a brief summary of results is presented in the following paragraphs.

The work on niobium and tantalum chemistry has resulted in the first syntheses of trimethyldichloroniobium and trimethyldichlorotantalum. These compounds are the first members of a previously unknown class; i.e., organometallic compounds of the transition metals of Group VA which have σ metal-carbon bonds. Thus, the chemistry of these compounds is of great interest, particularly in regard to bonding theory.

Investigations into the application of these new compounds with new methods of metal film deposition was also very productive. Preliminary experimental work in this area has shown that it is possible to deposit niobium and tantalum films on quartz or gold foil under much milder conditions than were required by the old processes. The new process involves the pyrolysis of trimethyldichloroniobium or trimethyldichlorotantalum at 700°C in vacuum. The films are smooth, shiny mirrors which appear uniform under microorganic examination. The niobium film has been shown to be a superconductor.

A principal advantage of the new method is that the required temperature is much lower than that of the old process which involved hydrogen reduction of the penta-halides in the gas phase. With the new process, deposition on a much greater variety of material is possible.

In addition, metal dysmitron is selective, occurring only on areas which have been heated. This method also permits films to be evenly deposited on the inside wall of a tube, a process that had been extremely difficult to accomplish by means of the older methods. It is, of course, possible to extend the new process to any metal which can be gold plated.

A Patent application has been completed and filed (Metal Film Deposition, Serial No. 470,902).

PUBLICATIONS AND REPORTS

1. "σ-Bonded Alkyl Compounds of Niobium and Tantalum Trimethyldichloroniobium and Trimethyldichlorotantalum," J. Am. Chem. Soc. 86, 4202 (1964).

2. Sigma-Bonded Alkyl Compounds of Niobium and Tantalum, and Applications to Vapor Phase Plating," Space Programs Summary 37-29, Aug. 1, 1964 to Sept. 30, 1964, p. 152.

3. Manatt, S. L., "The P^{31} Nuclear Magnetic Resonance Spectra of the Methyl Phosphines," Space Programs Summary 37-24, Oct. 1, 1963 to Nov. 30, 1963, p. 247.

4. Manatt, Stanley L., and Elleman, Daniel D., "The Relative Signs of Phosphorus-Proton Nuclear Magnetic Resonance Coupling Constants," J. Am. Chem. Soc. 85, 2664 (1963).

5. Manatt, S. L., and Elleman, D. D., "On the Relative Signs of Phosphorus-Proton Coupling Constants," Space Programs Summary 37-21, April 1, 1963 to May 31, 1963, p. 231.

6. Manatt, S. L., "Relative Signs of the P^{31} - H^1 and P^{31} - C - H^1 NMR Coupling Constants," Space Programs Summary 37-17, Aug. 1, 1962 to Oct. 1, 1962, p. 30.

7. Manatt, Stanley L., Elleman, Daniel D., and Wagner, Ross I., "NMR of Phosphorus Compounds. II. The Relative Sign of the Spin-Spin Couplings in Dimethylphosphine and Methylphosphine," in preparation.

8. Manatt, S. L., "NMR of Phosphorous Compounds. III. The Analysis of the NMR Spectrum of Triethylphosphine," in preparation.

APPLIED MATHEMATICS (129-04)

APPLIED MATHEMATICS
NASA Work Unit 129-04-01-01
JPL 329-40101-1-3120

STATISTICAL ESTIMATION THEORY

The continuous form of the estimation technique developed in Ref. 1 and 2 was specifically applied to the orbit determination problem, obtaining integral equations describing the time varying estimate and error covariance matrix of the orbital elements. The results are described in Ref. 3. Work is under way to develop a digital computer program to exploit and further analyze these results, as there exists the possibility of a real advantage in this method. Specifically, if data is taken at very close time intervals the numerical inversion of certain matrices arising in the discrete estimation technique can be a difficult problem because of ill-conditioning effects. On the other hand, introducing the continuous estimation technique can eliminate this difficulty and it is then possible to approximate the results of the continuous theory in a discrete manner without encountering numerical problems. It is also conceivable that in future missions data could be taken and processed continuously and this study develops the necessary theory and equations to accomplish this task.

The analysis developed in Ref. 1 and 2 has been extended and compared to similar work by Kalman, Bucy, Bryson and Johansen. A note describing these results (Ref. 4) has been submitted for publication in a technical journal. These analyses have been revised and will be submitted for publication to a technical journal (Ref. 5).

The error covariance matrix obtained with the continuous form of the sequential estimator has been compared with those obtained from two better known discrete forms of the estimator, where a simple model of an orbit determination problem is assumed. It is shown in Ref. 6 that the continuous form yields somewhat better results. For example, the accompanying Fig. 1 and 2 show the standard deviation of the error in the estimate of the speed v, when given continuous data of the form $\alpha(t) = vt + n(t)$ where $n(t)$ is correlated noise and t is the time from the beginning of the tracking interval. In Fig. 1 the results obtained are compared when the continuous form of the estimate is employed and it is assumed (1) the noise $n(t)$ is stationary, and exponentially correlated with correlation interval τ; or (2) the noise $n(t)$ is of nonstationary type. In Fig. 2 the results obtained are compared when the nonstationary noise model is assumed, and (1) the continuous form of the estimate is employed, or (2) the data is sampled at discrete times, adjacent readings are differenced, and the discrete form of the estimate is employed. This latter situation is essentially the data processing mode employed in the present JPL orbit determination program for counted doppler data.

A trip was made to MSC, Houston, to discuss the work in estimation theory described above with some of the people responsible for developing the orbit determination equations for the Apollo mission (E. Scheissen of MSC, S. Pines of AMA, et al.). Future liaison of this type is planned so that appropriate applications to the Apollo mission can be exploited and work at JPL directed accordingly.

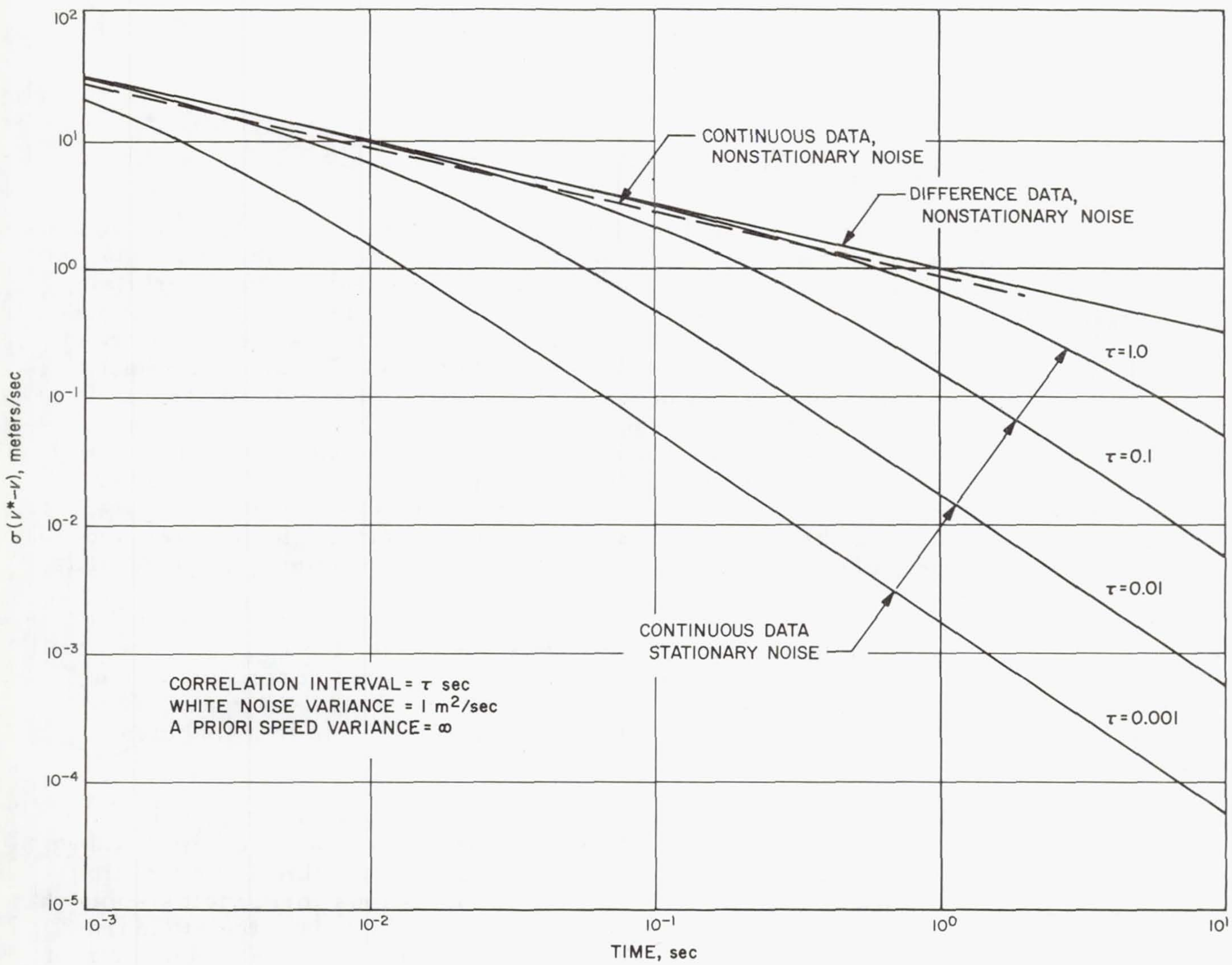


Fig. 1. Standard deviation of error in estimate vs tracking time

A Contractors Report Symposium was attended at GSFC and discussions were held with K. Squires of GSFC, S. Pines of AMA, R. Bucy of University of Maryland et al., on the current state of Statistical Estimation Theory and its application to the Orbit Determination Problem. As a consequence of these discussions, preliminary investigations have been initiated into the theory of nonlinear estimation. That is, rather than approximate the nonlinear problem by a linear one whose exact solution can be found and the process iterated as is currently done, it is proposed to find a method of approximating the exact solution to the nonlinear problem. The consensus of opinion indicates that, philosophically at least, this approach is more rational and esthetically pleasing.

OPTIMAL CONTROL THEORY

A new approach to optimal control theory has been formulated based upon a geometrical interpretation of an optimal trajectory. The analysis yields a simple

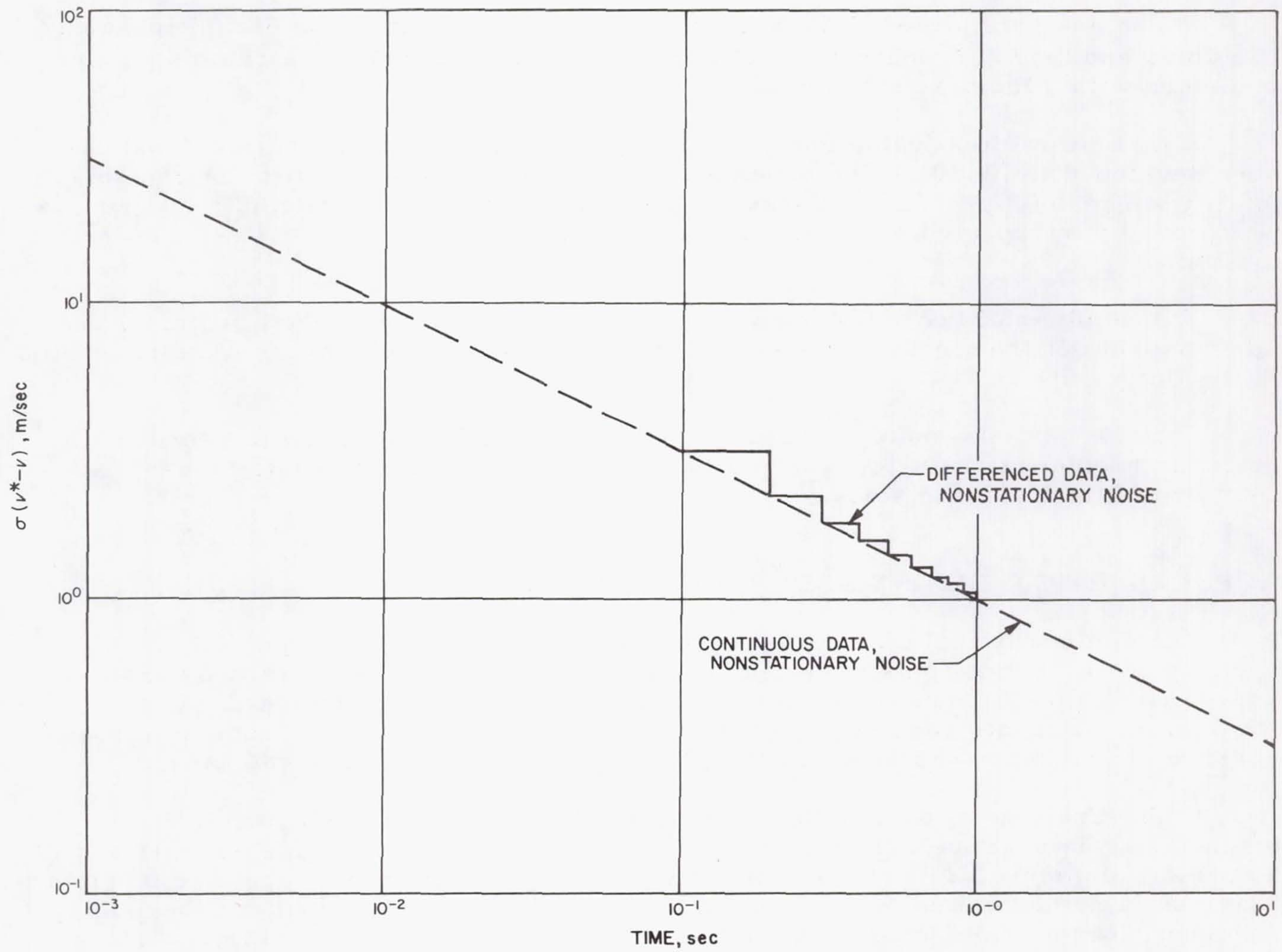


Fig. 2. Standard deviation of error in estimate speed vs tracking time

statement of the classical necessary and sufficient conditions for a minimum and several new results. Specifically, necessary and sufficient conditions for a "singular extremal" are obtained for the first time and the existence of an "incomplete extremal" is exhibited. This material has been submitted for publication in a technical journal (Ref. 7).

The analysis of Ref. 7 has been applied to the classical problem of describing geodesics in a Riemannian space (Ref. 8). The first necessary condition (Euler-Lagrange equations) describing an extremal arc is developed from the control theory point of view, and further necessary and sufficient conditions to be satisfied if the extremal so defined is to yield a minimizing arc are presented.

In Ref. 9 the Schwarz-Christoffel transformation has been applied to show that the Euler-Lagrange equations do indeed yield absolute minimal solutions.

The analysis of Ref. 7 is being extended to include the case of multiple control variables and "strong" control variations. This material should be completed and published within the next six months.

An optimal final value control technique for rocket vehicle trajectories has been developed (Ref. 10). The scheme is based upon an interpretation of controllability suggested by Ref. 7 and leads to a mathematical formulation of a steering law which can be interpreted as a rationalization of the well-known velocity-to-be-gained method.

A seminar of two 1 1/2-hour invited lectures on the material of Ref. 7 and other aspects of the theory and application of Optimal Control Theory were presented at the University of Texas.

In the next six-month period the application of Ref. 9 to the low thrust guidance problem is being considered but time and manpower limitations preclude a firm commitment to this study.

APPROXIMATION THEORY AND NUMERICAL ANALYSIS

A semianalytical method for solving ordinary differential equations with polynomial representations has been developed (Ref. 11). There are two versions: one which applies to equations where no approximate solution is known, and the other in the alternate case, such as occurs in celestial mechanics problems. One version of this paper has been submitted for publication in a technical journal.

The analysis of Ref. 11 has been applied to some problems in celestial mechanics. In practice it is usually necessary to use slowly varying quantities such as orbital elements. In Ref. 12 a set of equations is given which appear to be attractive from a numerical point of view. The set has been programmed and thoroughly checked. Numerical comparisons of the speed of this method with other standard methods for the case of simple perturbing forces is now being undertaken.

A simple and accurate scheme for the numerical evaluation of a finite Fourier series, similar to the method of Clenshaw for the evaluation of Chebyshev series has been developed (Ref. 13).

The "First International Conference on Programming and Control" which was held at the USAF Academy, Colorado, on 15-16 April 1965 was attended in connection with the research performed in numerical analysis.

OPERATIONS RESEARCH

In the area of Operations Research several studies have been conducted.

Two redundancy techniques for improving the reliability of a general spacecraft system were considered and compared (Ref. 14). The first involved simple paralleling while the second required control circuitry which directs operations through standby units upon failure of the primary.

Three studies were completed demonstrating the application of linear and dynamic programming techniques to operations research. The first (Ref. 15) illustrates the potential of Dynamic Programming as a tool for resolving spacecraft mission planning problems. The second (Ref. 16) considers a program planning problem designed to optimize the expected return of the program by optimally scheduling the flight spacecraft. The third (Ref. 17) was a tutorial paper on linear programming.

It is intended to extend these studies to develop those mathematical techniques suitable for the optimization of large complex systems.

In conjunction with the above studies the 27th National Meeting of the Operations Research Society of America (ORSA) at Boston on 6-7 May 1965 was attended.

APPLIED MATHEMATICS

The equations of motion for two coupled rigid bodies moving relative to each other in a known manner have been derived (Ref. 18). Applications include the equations of motion for the orientation of a spinning rocket with large antennas which move relative to the rocket. It is demonstrated in this paper that the problem is not equivalent to assuming a time-varying moment of inertia.

RELATIVITY THEORY

An interpretation of the meaning of coordinates as regards the line element of relativity theory has been developed (Ref. 19) and supports Ref. 20 in negating the ideas of Muhleman, Reichley, and Shapiro.

In the next six-month period it is planned to investigate the so-called 4th test of relativity proposed by Muhleman et al. in much more depth and detail.

The two-body problem has been analyzed using the classical Schwarzschild line element and the isotrophic line element of general relativity (Ref. 21). The resulting perturbative accelerations are due to the mass of the central body. The n-body problem is also analyzed using de Sitter's line element, which is an approximate solution to Einstein's field equations. An expression is developed which relates atomic time on Earth to ephemeris time, through the heliocentric orbital elements of the Earth-Moon barycenter. In order to relate the equations of motion to observation, the basic relativistic equations for computation of angular, radar and doppler measurements are included.

Three machine programs have been prepared for the algebraic manipulation of tensors in relativity and in classical mechanics for the IBM 7094 with the FORMAC system (Ref. 22). It is currently being checked out. In the near future it is anticipated that these programs will be extended to handle a larger variety of algebraic expressions. The subject of algebraic computations has been the theme of two meetings between JPL and IBM personnel in January and March of 1965 at JPL and IBM respectively at which an exchange of the pertinent developments and potential applications were considered.

SEMINARS

During this reporting period a sequence of short intensive coordinated seminars were conducted in the applied mathematics task area covering such topics as "Principles of Statistics," "Estimation Theory," "Theory of Approximation," "Matrix and Tensor Analysis," "Linear Programming," "Dynamic Programming," and "Relativity Theory," for the purpose of acquainting more JPL personnel with the concepts, techniques, and applications of these disciplines to their own fields and to extend and develop the mathematical capabilities of those engaged in applied research: An informal collection of notes were disseminated, some of which have been documented, e. g. (Ref. 17).

REFERENCES

1. Pfeiffer, C. G., Sequential Estimation of Correlated Stochastic Variables, TR 32-445, June 1963.

2. Pfeiffer, C. G., Continuous Estimation of Sequentially Correlated Random Variables, TR 32-524, October 1963.

3. Pfeiffer, C. G., Application of the Continuous Sequential Estimation Technique to Some Orbit Determination Problems, TM 312-546, 6 April 1965.

4. Pfeiffer, C. G., "On The Continuous Form of the Linear Filter," submitted to IEEE Transactions on Automatic Control, June 1965.

5. Pfeiffer, C. G., "Estimation of Sequentially Correlated Random Variables," to be submitted for publication.

6. Pfeiffer, C. G., A Simple Comparison of Three Ways to Process Continuously Counted Dopper Data, TM 312, to be issued.

7. Pfeiffer, C. G., "A New Approach to Optimal Control Theory," submitted to Journal of Franklin Institute 1965.

8. Pfeiffer, C. G., Necessary and Sufficient Conditions for a Riemannian Geodesic to Yield Minimum Arc Length, TM 312, to be issued.

9. Lass, H., "Minimal Extremals in the Calculus of Variations," SPS No. 37-30, Vol. IV, 31 December 1964.

10. Pfeiffer, C. G., A Technique for Optimum Final Value Control of Powered Flight Trajectories, TR 32-447, 1 May 1965. Also submitted to AIAA Journal, June 1965.

11. Kizner, W., "Error Curves for Lanczos' Selected Points Method," SPS No. 37-31, Vol. IV, 28 February 1965. Also submitted to Computer Journal.

12. Kizner, W., A Formulation of the Variation of Parameter Equations for Rectangular Elements, TM 312-535, 22 February 1965. Also Addendum No. 1, 18 March 1965.

13. Kizner, W., The Numerical Evaluation of Fourier Series, TM 312-525, 1 February 1965.

14. Billy, J. M., The Application of Redundancy to Improve System Reliability, TM 312-531, 9 February 1965.

15. Billy, J. M., A Dynamic Programming Simulation of Spacecraft Mission Planning, TM 312-542, 1 April 1965.

16. Billy, J. M., AMOS 2--A Basic Program Planning Analysis, TM 312-563, 10 June 1965.

17. Brouke, R. D., Basic Principles of Linear Programming and Possible Applications in Space Research, TM 312-523, 25 January 1965.

18. Lass, H., Euler's Equations of Motion for Pseudo-Rigid Body Dynamics, IOM 312.6-52, 4 March 1965.

19. Lass, H., "Coordinates in the General Theory of Relativity," SPS No. 37-32, Vol. IV, 30 April 1965.

20. Lass, H., A Critique of a Paper by D. O. Muhleman and P. Reichley on 'Effects of General Relativity on Planetary Radar Distance Measurements,' TM 312-515, 4 January 1965.

21. Moyer, T., Relativistic Equations of Motion, TM 312-548, May 1965.

22. Broucke, R., Three Examples for Automatic Manipulation of Algebraic Expressions in Celestial Mechanics, IOM 312.8-6, 28 January 1965.

Page Intentionally Left Blank

LUNAR AND PLANETARY FLIGHT MECHANICS
NASA Work Unit 129-04-01-02
JPL 329-40201-1-3120

ASTRODYNAMICAL CONSTANTS AND EPHEMERIDES STUDIES

Reduction of Mariner II data is in progress and should be completed in the next six-month period. Progress to May 1965 is described in a paper presented at COSPAR IUTAM, IAU Joint Symposium on the Trajectories of Artificial Celestial Bodies as Determined from Observations in Paris, April 20-23, 1965 (Ref. 1). This paper will appear in the proceedings of the symposium to be published by Springer - Verlag, M. Ray Ed.

As the mission requirements of our space program become more exacting in the coming years, it will be necessary to improve the accuracy of existing planetary ephemerides. Ephemeris improvement studies are planned utilizing more accurate estimates of certain astronomical constants obtained from recent Ranger and Mariner flights, from recent planetary radar-bounce data, and from optical data taken by astronomical observations. This work will proceed in close communication with the U. S. Naval Observatory, and its utility to the International Astronomical Union in establishing an international ephemerides is a long-term goal.

SELENODESY EXPERIMENT

A proposal submitted last September (Ref. 2) to analyze radio tracking data from the Langley Lunar Orbiter to obtain a more accurate description of the lunar gravity field has been accepted by NASA. In anticipation of this approval several computer studies had been initiated. These involved (a) Conditions under which the SPODP converges for lunar orbiters, (b) Evaluation of Sensitivity Coefficients for radiation pressure and certain of the harmonic coefficients using the JPL-TRAJ program, (c) Evaluation of the sensitivity of some of the higher order harmonic coefficients using JPL-TRAJ, and (d) Evaluation of the accuracy to which the harmonic coefficients can be evaluated, using the lifetime program for Lunar Orbiter (LOLP). To date there is no report on (a) and (b); (c) and (d) have been documented (Ref. 3 and 4).

The LOLP is in the process of being updated to include additional harmonics, radiation pressure, relativistic effects, the shadow equation, and a plot of partial derivatives. This work has been documented in a series of IOM's and RFP's which will not be listed here.

In addition to the above, a short study of the precision of integration was conducted and is documented in Ref. 5. Reference 6 describes the potential model installed in the single precision trajectory program for lunar orbiter studies. Normal matrices are being computed to determine how well certain harmonics can be determined. Data have been generated on the single precision program for comparison with the averaging programs.

Related work involves an attempt to try to determine the offset of the center of mass of the Moon from the center of figure from Ranger results.

A study group has made a survey of the methods of computing orbits, in the process of which every major organization in the country so involved was contacted. The results of the study are contained in Ref. 7.

JPL made a presentation of the material for the selenodesy proposal to the Selenodesy Working Group of the Planetology subcommittee of the Space Sciences Committee (NASA) Boeing, Seattle on March 25, 1965 and the meetings of the Lunar Orbiter Trajectories at Houston, on January 20, 1965 and the AIAA at New York City on January 25-27, 1965 were attended in conjunction with this work.

The activities in this area will continue and be expanded to include further studies of sensitivity coefficients, evaluation of harmonics, use of a general perturbation program and appropriate coordination and liaison between JPL and other cognizant agencies in the next six months.

TRAJECTORY ANALYSIS

Double Precision Trajectory Program (DPTRAJ)

A double precision Cowell trajectory program is being developed. This program is required for the high accuracies needed for advanced missions, and to make full use of the capabilities of Earth-based radio guidance. It will also be used as a subroutine for the double precision orbit determination program which will have the capability of improving the knowledge of various physical constants. This work has been mainly in the area of writing equations for an improved mathematical model, such as in Ref. 8. The operating characteristics of the single precision program are being studied with a view to recommending desirable developments for the double precision program. For example, several variations of parameter methods may be studied to see if this should be incorporated in DPTRAJ. These plans are outlined in Ref. 9.

In an attempt to improve mathematical model accuracy, a study of nongravitational trajectory perturbations such as radiation pressure, attitude control jets, etc., has been conducted. This is reported in Ref. 10. A by-product of this work is reported in Ref. 11.

Although none of the actual program development is being supported by this task the final program will be an important research tool.

Satellite Lifetime Program

Lifetime programs are being developed for lunar satellities and Mars satellites. Two programs have been developed using the Krylof-Bogoluibov method which averages perturbations over one cycle. One program includes drag and the other does not. Both programs include 3rd body and oblateness effects. The programs have been checked against other averaging programs and against an integrating program. One of the programs is currently in use for lunar orbiter studies (reported elsewhere). When the drag program is completed it will be used for studying Mars orbiter lifetimes which will be reported in the next period. Other lifetime methods, such as that proposed by Taratynova, will also be studied.

Other Advanced Mission Topics

There are three other advanced mission topics on which preliminary work has been done and will be pursued further. Reference 12 has shown that broken plane transfers (i.e., a trajectory using a plane change maneuver in midflight) can produce desirable changes in target geometry. It can also produce advantages in target departure geometry. Reference 13 has shown that broken plane transfers can also produce payload gains for orbiter missions even when operating away from the 180 deg transfer energy ridge. An optimizing procedure for these trajectories has been formulated and will be programmed for further studies.

Another topic of interest is Earth-comet missions. A study group working on such a mission is expected to be formed soon and trajectory support is hopefully being planned.

An interesting class of lunar trajectories has been described in Ref. 14, 15, and 16. These orbits are similar to the Moon's orbit but inclined to it. Further work on these orbits may be desirable.

COMPRESSION OF DOPPLER TRACKING DATA

Experimentation with data compression to date has been centered about the Mariner II-data, but little has been accomplished on this project in the last six months because of manpower and time limitations, and the press of other work. The results of this investigation are not conclusive enough for publication at this time. However, in the next six-month period an attempt will be made to achieve an order of magnitude or so reduction in the quantity of doppler data without a significant loss in information.

CELESTIAL MECHANICS

In the study of periodic orbits in the three-body problem, initial conditions have been prepared on punched cards and on microfilm for about 1100 periodic orbits, for publication as a technical report in the near future. The data had been previously obtained but have now been converted to double precision with about 10-place accuracy.

Regularized equations of motion have been prepared for the three-dimensional circular restricted three-body problem (Ref. 17), and for various nonconservative systems such as the restricted four-body problem, the elliptic restricted three-body problem which has been published in a technical journal (Ref. 18), and the Earth satellite problem with atmospheric drag (Ref. 18).

A preliminary investigation of the pulsations of the Earth and the Moon has been initiated (Ref. 20). The possibility of detecting the lunar bodily tide with a transponder at rest on lunar surface exists, but the investigation indicates that with the models considered for the Earth and Moon, and a transponder in a favorable position, that the best capabilities of Earth-based tracking would still fall about one order of magnitude short of yielding any results since the effect on range rate from this source is approximately 2.8×10^{-6} m/sec.

It is planned to continue this study of lunar and terrestrial pulsations in more detail by numerical integration of the appropriate equations of motion using the JPL Ephemeris tapes.

ASTRODYNAMICS SYMPOSIA

A monthly series of symposia on Astrodynamics for the Los Angeles area has been initiated by JPL. The first meeting was held June 15, 1965 at JPL, and the next two meetings will be held at STL in July and NAA in August. The purpose of these symposia is to provide a forum for the specialists in Astrodynamics and facilitate the interchange of ideas and current developments.

REFERENCES

1. Anderson, J. D., and Warner, M. R., "Determination of the Masses of the Moon and Venus and the Astronomical Unit from the Radio Tracking of Mariner II," presented at IAU-COSPAR symposium, Paris, April 20-23, 1965.

2. Proposal for Analysis of Radio Tracking Data from the Lunar Photographic Orbiter, September 28, 1964.

3. Sturms, F., Effects of Moon's Gravitational Harmonics on a Lunar Orbiter, TM 312-512, December 31, 1964.

4. Lorell, J., Preliminary Evaluation of Sensitivity Coefficients for the Selenodesy Experiment, TM 312-562, June 7, 1965.

5. Lorell, J., Accuracy of the DBH07 Orbit Computations, IOM 312.6-41, January 14, 1965.

6. Sturms, F., New Lunar Potential Model for Lunar Orbiter Operations Program, RFP 312-373, February 16, 1965.

7. Cutting, E., Report of Study Group, IOM 312.4-165, January 31, 1965.

8. Sturms, F., Specification of Mars Coordinate System for DPTRAJ, IOM 312.4-168, February 4, 1965.

9. Report of Study Group, Orbiter Computing Methods Study Group, IOM 312.4-165, January 31, 1965.

10. Flandro, G., "Non-Gravitational Perturbations on Minimum Energy Transfer Orbits," SPS 37-30, Vol. IV, pp. 6-14, December 31, 1964.

11. Flandro, G., "Effects of Non-Gravitational Perturbations on Minimum Energy Transfer Orbits," SPS 37-33, Vol. IV (to be published).

12. Feitis, P., Impulsive Non-Stop Multiple Planet Trajectory Capability in SPARC, RFP 312-424, June 2, 1965.

13. Bollman, W. E., On the Application of a Midcourse Impulse to Alter Planet Arrival Geometry, TM 312-454, June 7, 1965.

14. Feitis, P., Use of a Broken-Plane Trajectory for Mariner-Mars 1969, IOM 312.4-148, December 29, 1964.

15. Kirhofer, W., "Conic Approximations Used in Circumlunar Trajectories," SPS 36-11, November 1, 1961.

16. Kirhofer, W., Lunar Flyby Trajectories Resulting in Kirhofer Orbits, IOM 312.1-11, June 11, 1965.

17. Broucke, R., The Three-Dimensional Restricted Three-Body Problem, TM 312-511, January 29, 1965.

18. Broucke, R., "Regularization of the Plane Restricted Three-Body Problem," Icarus, Vol. 4, No. 1, February 1965.

19. Broucke, R., "Symmetrization of the Two-Body Problem," SPS No. 37-33, Vol. IV, June 1965.

20. Efron, L., Lunar Bodily Tides and Range Rate of Spacecraft at Rest on the Lunar Surface, IOM 312.8-10, April 15, 1965.

Page Intentionally Left Blank

NUMERICAL ANALYSIS
NASA Work Unit 129-04-04-01
JPL 329-40301-1-3170

The basic objective of this work unit is to develop and analyze general computer-oriented algorithms.

Systematic studies have been made of the accuracy of the double-precision second-sum numerical integration subroutine used in the computation of the planetary trajectories (SPS No. 37-31, 37-32, and 37-33). For example (see Fig. 1), it was demonstrated that in integrating the Cowell form of the differential equations for two body Keplerian motion in a circular orbit this integration subroutine, using 50 steps per orbit, was correct to greater than ten decimal digits throughout 500 orbits.

In this same example the vis-viva (energy) integral and the angular momentum integral, computed as a function of the numerically integrated position and velocity, remained constant to about 14 decimal places throughout the run. This illustrates the fact that the accuracy of an integral cannot be used as a direct measure of the accuracy of the numerical solution of a differential equation.

Another accuracy test which has been used by some writers consists in integrating an initial value problem from t_0 to t_1, then re-starting with the computed value of the solution at t_1 and integrating back from t_1 to t_0. The error observed at t_0 is then suggested as a measure of the accuracy of the procedure. In our investigation, cases occurred in which the maximum error during the forward integration from t_0 to t_1 was ten times as large as the final error at t_0.

One result of this investigation is a set of graphs which relate integration step size, order of the integration method, eccentricity of elliptical trajectory and accuracy of numerical solution. These graphs are useful in choosing the step size to attain a desired accuracy for near-elliptical trajectories such as, for instance, the planetary orbits needed in ephemeris development.

Further work along these lines will include a critical comparison of summed and unsummed integration methods.

A method has been specified for the least squares fitting of a paraboloid to a discrete set of data points. This procedure will be used by the Telecommunications Division in the study of antenna distortion. This is a nonlinear least squares problem and the new method incorporates a more exact mathematical model than was used previously. Reported in SPS 37-31, Vol. IV, and SPS 37-32, Vol. IV.

Improved error bounds were derived for Everett interpolation formulas with throwbacks. These bounds were used to study the error associated with various interpolation formulas for accessing the JPL Ephemeris. A report on this work is being written.

For a problem arising in radiation physics mathematical analysis was performed leading to a nonlinear system of differential equations and integral equations having singular kernels, nonlinear boundary conditions, and discontinuous solutions. New numerical methods for computing solutions were derived and successfully applied. This will be reported in SPS No. 37-34, Vol. IV.

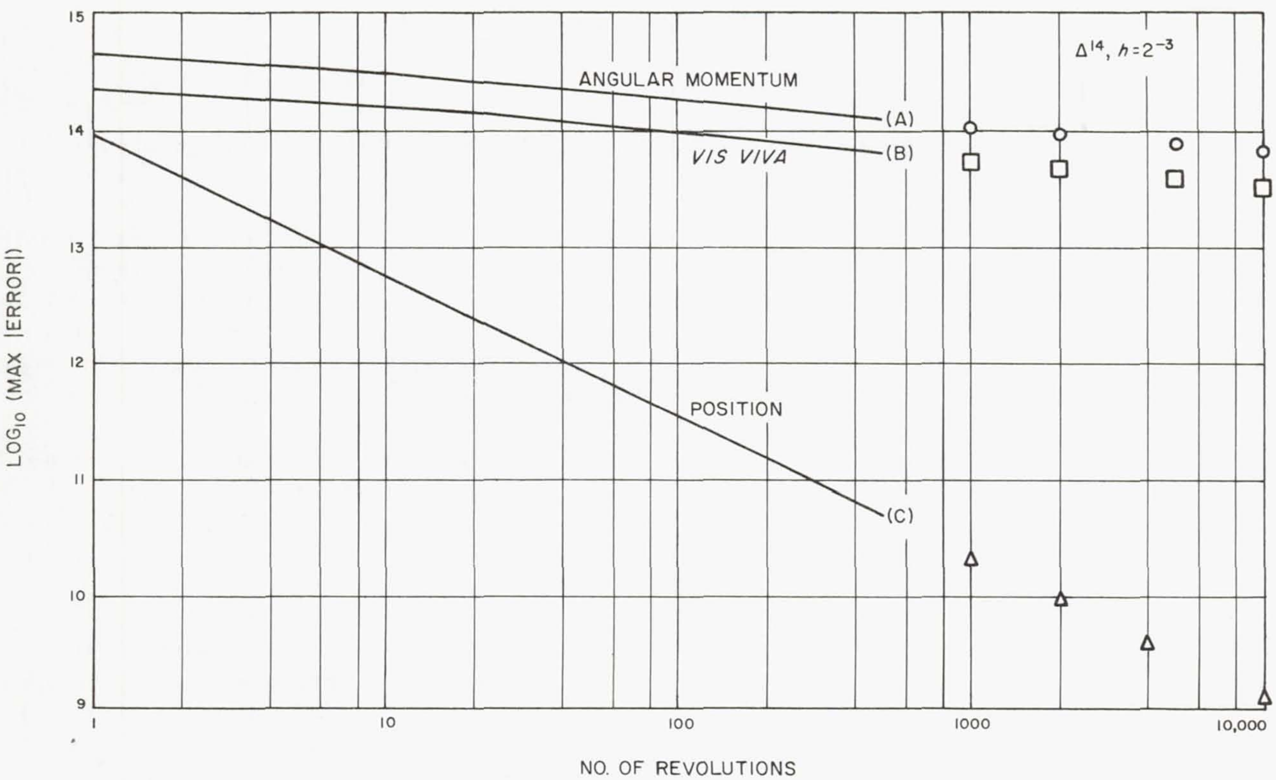


Fig. 1. Cumulative maximum error of solution

CELESTIAL MECHANICS
NASA Work Unit 129-04-04-02
JPL 329-40401-1-3170

One of the primary activities under this work unit is the continuing development of the JPL planetary and lunar ephemerides.

These ephemerides are tables giving the position and velocity of each planet and the Moon, and the nutations in longitude and latitude with their time-derivatives, as a function of time (ephemeris time).

The motivation for developing ephemerides at JPL was the need during the Venus radar bounce experiments in 1961 (Ref. 1) for planetary velocity data with more smoothness and consistency than was obtainable by the numerical differentiation of planetary positions obtained from standard astronomical ephemerides. The general approach taken in developing ephemerides at JPL is described in Ref. 2 and 3. Some details of the problem of achieving consistency are reported in SPS 37-29, Vol. IV, pp. 61-64.

For the support of spacecraft projects and ground-based planetary and lunar radar experiments, these ephemerides have been organized into a system of magnetic tapes and associated subroutines making the data available to computer programs in the IBM 7094 computers (Ref. 4 and 5). This JPL Ephemeris Tape System provides a consistent model of the solar system and has been distributed on request to NASA centers and contractors.

During FY 1965 improvements have been made in the efficiency of computer programs used in ephemeris development. Programs have been converted to Fortran IV to make more efficient use of the IBM 7094 hardware double-precision. Difficulties which previously prevented the production of an integrated Neptune ephemeris have been overcome.

Currently the mathematical model of planetary motion used in numerical integration of planetary orbits is being extended to introduce separately the perturbations of the Earth and the Moon on other planets. Following this, the program will be extended to permit the introduction of classical optical planetary observations.

A harmonic analysis was made of the residual curves of the integrated ephemerides of the outer planets. The principle components of the residual curves could be identified with terms which had been intentionally omitted in the source ephemeris. A JPL TM reporting this work is currently in production. The report will be summarized in SPS 37-35, Vol. IV.

Improvements have been made in the mathematical model of ground-based lunar and planetary radar experiments. This model has been incorporated into a new double-precision computer program (RADAR1) which is used to provide the range and doppler predictions needed for the execution of these experiments.

The data compression technique of representing range and doppler each by one polynomial per day, which was developed in November 1963 and introduced into operational use in April 1964 has been continued in the new program. Currently, this new program is being extended to handle the analysis of data obtained in ground-based lunar and planetary radar experiments.

Further modifications are being designed to support changes in experimental technique associated with the new 210-ft Mars site antenna.

REFERENCES

1. Muhleman, D. O., Holdridge, D. B., and Block, N. The astronomical unit determined by Radar reflections from Venus, TR 32-221, March, 1962.

2. Peabody, P. and Block, N., "Planetary Position - Velocity Ephemerides Obtained by Special Perturbations," AIAA Journal, Vol. 1, No. 12, December, 1963, pp. 2812-2815.

3. Devine, C. J., PLOD II: Planetary Orbit Determination Program for the IBM 7094 Computer, TM 33-188, April, 1965.

4. Peabody, P. R., Scott, J. F., and Orozco, E. G., Users Description of JPL Ephemeris Tapes, TR 32-580, March, 1964.

5. Peabody, P.R., Scott, J. F., and Orozco, E. G., JPL Ephemeris Tapes E9510, E9511, and E9512, TM 33-167, March, 1964.